25th Annual Symposium

22nd & 23rd September 2020

WEBINAR

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25th Annual Traffic Signal Symposium
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Day 1 Closing Address
John Nightingale – JCT Consultancy

Close 15.55

25th Annual Traffic Signal Symposium
PROGRAMME – Day 2 :

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John Nightingale – JCT Consultancy

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Reserved Session
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Reserved Session
TBC

Symposium Closing Address
John Nightingale - JCT

Close 15.10

Symposium Webinar Partners

It has only been possible to bring the Free to attend Webinar to our audience by the kind financial and content support of our Webinar Partners. Sincere thanks from JCT to them all

Integrated Traffic Services

Symposium Papers

In part due to the nature of global events this year and the pressure that many of our speakers are under there are only a limited number of written papers to accompany the Symposium this year.

Our sincere thanks go to all speakers and in particular to the contributors whose work is reproduced here.

Traffic Signal Symposium 2020

Session One

Paper Transforming Cities Fund Nottingham – Derby. Providing Centralised Traffic Signal Bus Priority

By Chris Gough - VIAEM

Transforming Cities Fund - Nottingham & Derby Providing Centralised Traffic Signal Bus Priority Via East Midlands

Introduction

The Transforming Cities Fund (TCF) aims to improve productivity and spread prosperity through investment in public and sustainable transport in some of the largest English city regions and was first announced in November 2017.

Derby and Nottingham submitted a combined bid and were successful in receiving funding in the first tranche of TCF funding with a value of £8.4m which included a £5.045m Public Transport Technology Package.

This paper explains the development and implementation of one keystone of the public and sustainable transport infrastructure in Derby & Nottingham – Central Bus Traffic Signal Priority.

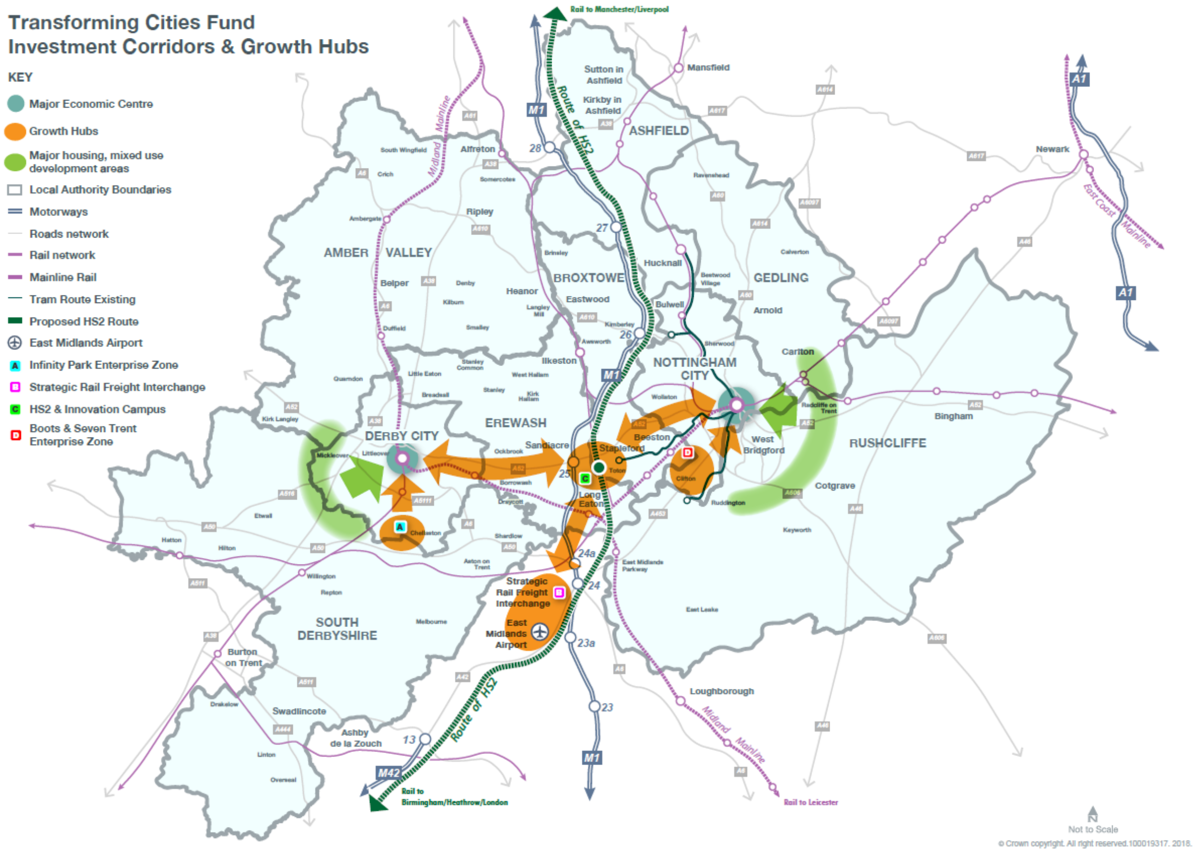


Figure 1 - Derby & Nottingham Transforming Cities Bid Area

Local Bus Traffic Signal Priority

Nottingham and Nottinghamshire has a long and varied history of providing bus priority at traffic signals. Methods of detecting buses in mixed traffic lanes have varied over the years. Tag based local detection systems such as Siemens SIETAG have been installed, Microsense MSEL and Applied Traffic algorithm detector pack systems and local radio systems such as the INIT LISA system.

Between 2012 and 2018 over 70 junctions were fitted with the INIT LISA bus priority system which uses local bus radio to transmit a request from the bus to the local traffic signal controller allowing bus priority to be implemented through local Hurry Calls, MOVA or sent back to SCOOT for central control. The advantage of the INIT LISA unit system over the loop detection systems is the bus request trigger can be set to only activate if the bus is behind schedule. The disadvantages of the INIT system is it is only used by Nottingham City Transport and one Trent Barton route within Nottingham and the surrounding area. The system requires bespoke equipment on the bus and within the traffic signal controller. The system also requires bespoke equipment in the bus operator back office.

Figure 2 - Local Bus Priority

The local radio system requires management and maintenance of street equipment. There is also little feedback on the operation and frequency of bus priority requests.

Centralised Traffic Signal Bus Priority

A central traffic signal bus priority system requires the bus to monitor its GPS position and when it reaches predefined locations the bus will generate a priority request trigger message. The priority trigger message is sent back to the system suppliers back office server. The back-office server then forwards the request to the appropriate UTC system, usually via a virtual private network (VPN). The priority request can be used to request priority at the traffic signals being approached by the bus.

Via East Midlands (ViaEM) was commissioned by the Derby & Nottingham Transforming Cities Area to project manage the provision and system implementation of a centralised traffic signal bus priority system. Via East Midlands is a company owned by Nottinghamshire County Council and provides sustainable highways services for Nottinghamshire and across the wider East Midlands region.

The central traffic signal bus priority solution requires no additional bus equipment as the requests are processed and sent through the electronic ticket machine

Figure 3 – Basic Central Bus Priority

The complications of providing central traffic signal bus priority multiply when dealing with multiple highway authorities, Urban Traffic Control (UTC) centres and Bus Operators.

Transforming Cities Fund - Nottingham & Derby Providing Centralised Traffic Signal Bus Priority Via East Midlands

The area has the following Highway Authorities:

- Nottingham City Council
- Derby City Council
- Nottinghamshire County Council
- Derbyshire County Council
- Highways England

Traffic Signal junctions in the region are currently connected in to two UTC Centres – with Derbyshire County planning to develop a UTC Centre

1. Nottingham City / Nottingham County / Highways England located in Nottingham
2. Derby City
3. (Derbyshire County Council planned UTC Centre)

The major Public Transport Operators in the area:

- Nottingham City Transport
- Trent Barton
- Stagecoach
- Arriva
- CT4N
- Marshalls

To provide central traffic signal bus priority over the large geographical area covered by Nottingham & Derby TCF a modular and scalable approach was required. The decision was made to implement a central system for bus traffic signal priority and to pass the traffic signal priority requests through a Traffic Signal Priority (TSP) Data Broker.

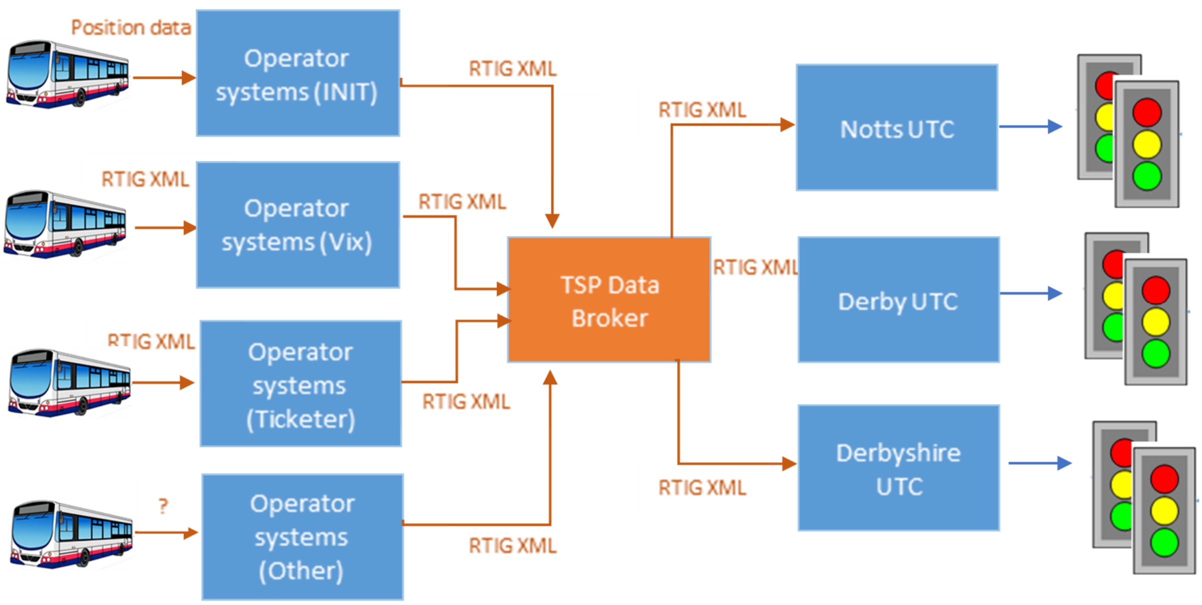


Figure 4 - Central Bus Priority Data Broker TCF Nottingham & Derby (source Ben Hallworth)

Transforming Cities Fund - Nottingham & Derby Providing Centralised Traffic Signal Bus Priority Via East Midlands

Benefits of Bus Traffic Signal Priority Through a TSP Data Broker

The proposal to introduce a TSP Data Broker reduces the number of connections from operator systems to UTC's which minimises connection costs and linkage failures. The TSP Data Broker will handle different connection types from different operator systems.

The TSP Data Broker can be programmed to send only the bus requests that are required to the UTC server. This enables filtering of the bus requests and prioritising of bus requests for particular routes and particular times of day. This granular approach may not be necessary for most junctions but can be used at particular locations in a targeted way to maximise bus benefit whist balancing delays to other users.

The TSP Data Broker solution allows cross boundary bus movements to send requests to different UTC systems as they cross from one UTC area to the next. The TSP Data Broker solution also enables priority requests to be monitored and dashboards to be produced automatically for all system data.

Trapeze Group NOVUS-TLP Data Broker

The NOVUS- TLP system was selected to provide the TSP Data Broker for the bus priority system across the Derby & Nottingham Transforming Cities Fund area. The NOVUS-TLP provides all the benefits of the Central Bus Priority Data Broker solution. The system has a web-based data input for junction trigger data and dashboard monitoring.

Junction triggers are located on the approaches to the traffic signal junction and on the exits from the junction. The junction triggers are placed in the system using a web interface. Users can therefore access the system from a variety of devices and locations, perfect in the event of a global pandemic. Junction triggers are placed and can be moved interactively on a map. ViaEM have been populating the system with junction details and trigger locations during the summer of 2020.

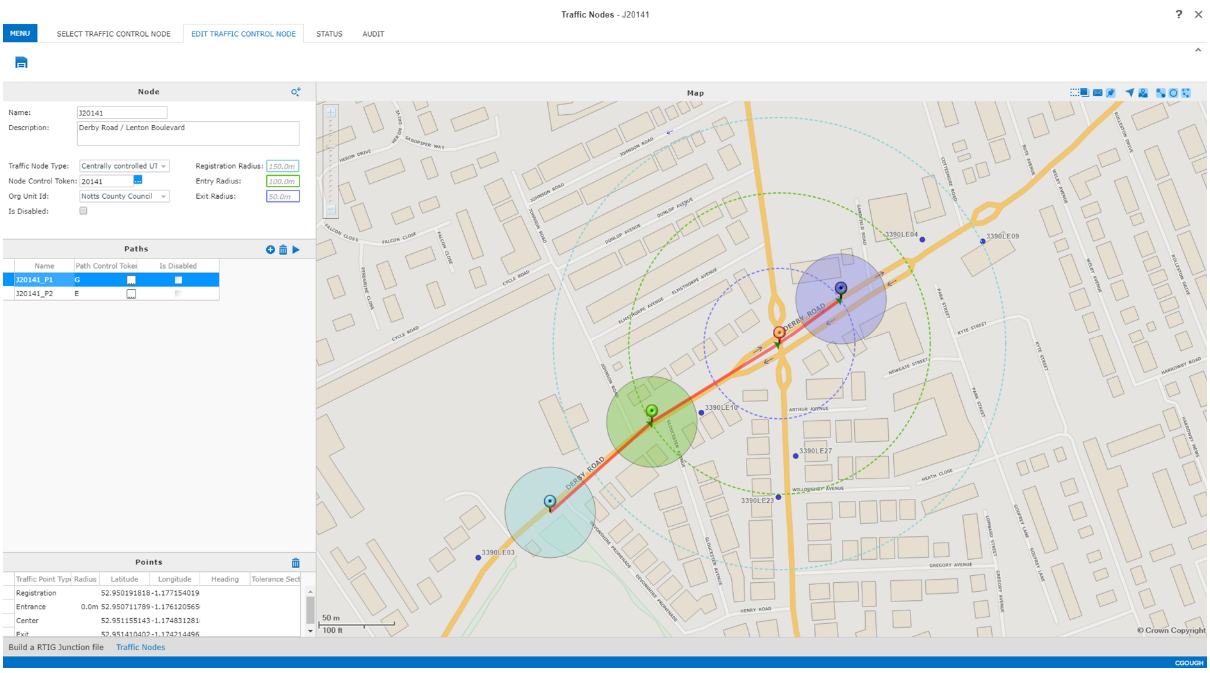


Figure 5 – NOVUS -TLP Bus Priority Trigger Input Interface

The trigger locations are exported from NOVUS-TLP as a file from the web page which is uploaded into the bus operators ticket machine systems. A vehicle with the correct criteria including location, direction and route entering the trigger zone will send a trigger through to the NOVUS-TLP TSP Data Broker. The TSP Data Broker will then pass the request for priority onto the relevant UTC for the junction.

ViaEM have been working with Trapeze on the NOVUS-TLP dashboards to enable simple and timely monitoring of bus priority request through the system. The TSP Data Broker and bus operator feeds have been configured to pass all trigger requests into the system even if the bus is ahead of schedule. This volume of requests enables monitoring of trigger levels to highlight drops in system performance or linkages into the system that can be investigated.

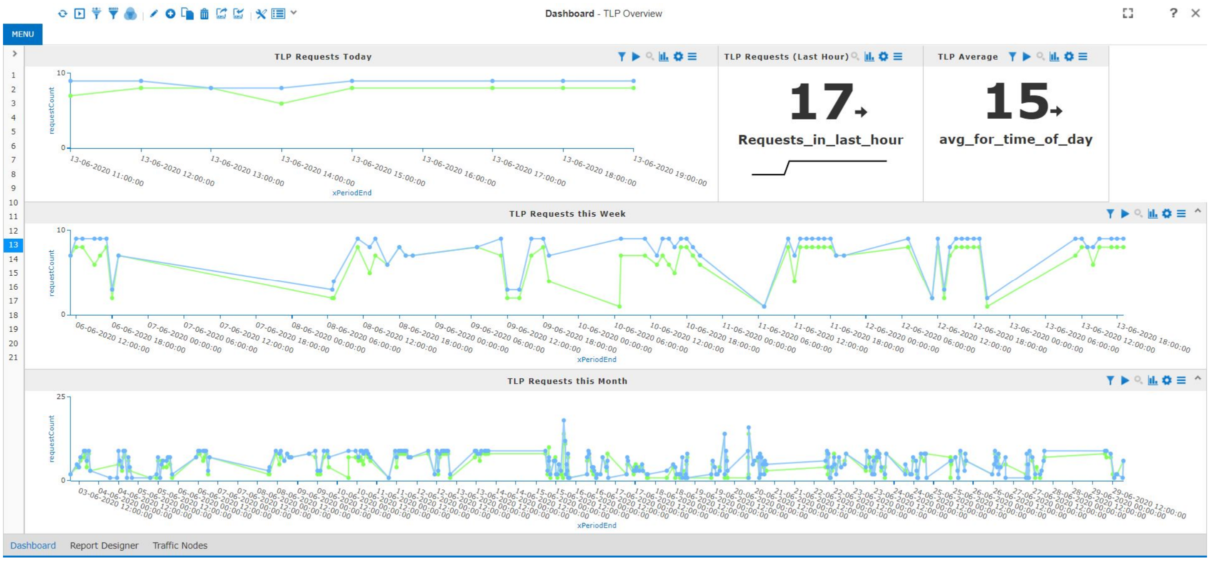


Figure 6 – NOVUS -TLP Bus Priority TLP Overview Dashboard

To enable a targeted approach to improving junction performance for public transport services a dashboard view has been developed that highlights the highest and lowest average travel time through junctions within the system.

Transforming Cities Fund - Nottingham & Derby
Providing Centralised Traffic Signal Bus Priority
Via East Midlands

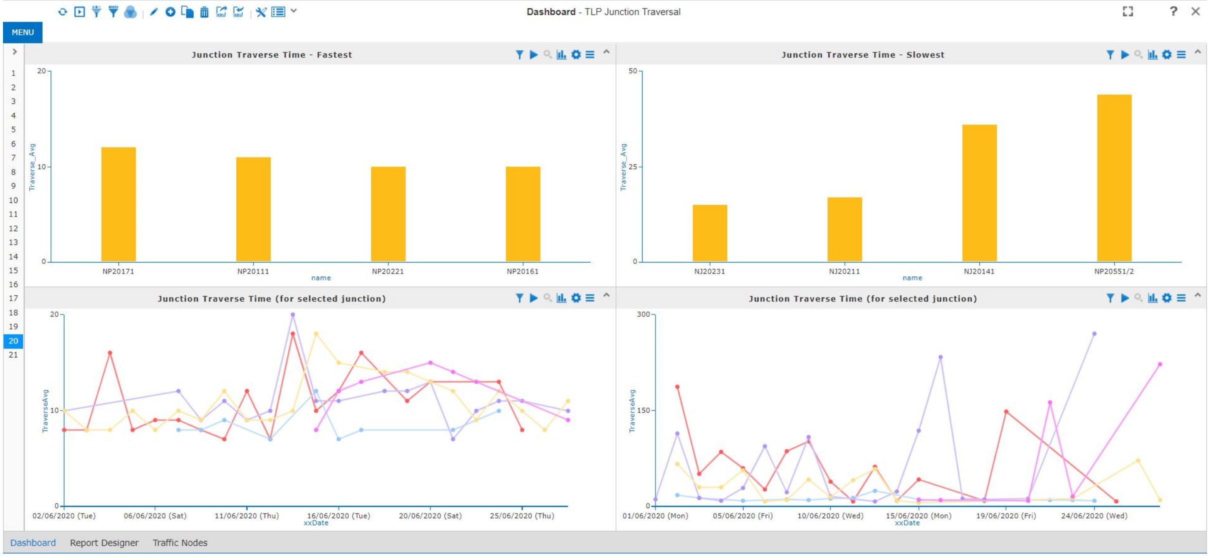


Figure 7 – NOVUS -TLP Bus Priority TLP Junction Traversal Dashboard

This dashboard enables engineers to assess where junctions are causing significant delays to bus services. The data can be filtered by day and time to narrow down when junction performance is an issue. Using UTC junction timing logs and CCTV recording could allow for specific improvement strategies to be developed and implemented to improve public transport service journey times and reliability.

Derby & Nottingham Centralised Traffic Signal Bus Priority Implementation

The bus operator CT4N was chosen as the test operator for phase 1 of the central bus priority junction implementation along Derby Road between Nottingham City Centre and QMC Hospital. Junction upgrades were carried out to junctions and pedestrian crossings along this corridor during summer 2019 to provide SCOOT control and enable central bus priority. These junction upgrades were project managed by ViaEM for Nottingham City Council.

Transforming Cities Fund - Nottingham & Derby Providing Centralised Traffic Signal Bus Priority Via East Midlands

The Nottingham Siemens UTC system was upgraded to enable central bus priority and to accept the VPN connection from the NOVUS-TLP Data Broker during spring 2020. Ticketer provide ticket machines for CT4N and the connection from the Ticketer server into the NOVUS-TLP system was also completed and commissioned in spring 2020. Following SCOOT database setup and testing, this was a very proud moment:

> We just had our first real bus priority call!
>
> Mo 13:52:18 B38 N20221E Bus 97 E 1 R 5 T 0 Bc 12 Ext 7
>
> Yay!

Figure 8 – First Bus Priority TLP Message

Nottinghamshire County Council also provided funding during 2019-2020 to upgrade junctions around Mansfield Town centre and the corridor out to Kings Mill Hospital.

As of August 2020 there are 237 junctions in the Derby & Nottingham NOVUS-TLP TSP Data Broker system.

Derby & Nottingham Centralised Traffic Signal Bus Priority - The Future

Derby & Nottingham area were successful in a bid for Transforming Cities Fund 2 (TCF2) funding to a value of £161 million. The provision of bus priority using the centralised system is a significant part of the proposals with traffic signal upgrades specified at 64 junctions in Nottinghamshire and 68 installations in Nottingham City. Junction upgrades are also planned for sites across Derby City and Derbyshire as part of TCF2.

Trent Barton have a Ticketer based system and are planning to connect into the bus priority system during autumn 2020. Stagecoach have a ticket machine and back office system provide by VIX and are also planning to connect into the system in summer of 2020. These connections will dramatically increase the number of buses sending requests through the system.

As part of any traffic signal installation upgrade or refurbishment scheme connection into the bus priority system will be part of the standard specification. ViaEM will be designing and project managing TCF2 upgrades over the next 3 years, so a busy time ahead.

Traffic Signal Symposium 2020

Session One

Paper Real Time Optimiser - the latest from the streets of London.

By Irfan Shaffi - TfL and Felix Rudolph - Siemens Mobility

Real Time Optimiser – the latest from the streets of London.

Irfan Shaffi (Transport for London) & Felix Rudolph (Siemens Mobility)

Introduction

Siemens Mobility and Transport for London, in collaboration with the University of Southampton, are working to create the Real Time Optimiser (RTO) solution that will deliver a new era of traffic management and control.

A key deliverable of this project is a newly engineered Urban Traffic Control (UTC) system, which paves the way for the development of an entirely new adaptive algorithm that TfL will use to replace SCOOT, a solution that has been in place in the capital for three decades.

Scope of this year's JCT presentation

This JCT presentation will explain the challenges that cities like London are currently facing and are likely to face in the future, such as population growth, fast changing travel patterns, new modes of transport and evolving technology. TfL will discuss their vision for system evolution and the requirements for RTO and future adaptive control, and Siemens Mobility will provide an update as to the development status, approach, and expectations of the new adaptive control solution that forms a key deliverable of the RTO development.

RTO and a new adaptive control algorithm

TfL and Siemens Mobility view the ten-year RTO project as a long-term partnership that will allow London's road network management system to be upgraded and optimised to embrace the diverse challenges that the city's transport network faces over the next decades. But it will also provide a solution that will be of value to other cities around the world – cities of all sizes and complexities.

The current Mayor of London's Transport Strategy emphasises how important healthy streets, air quality and crucially a reliable and sustainable public transport system are for all of London. To meet these aims, a change in approach and departure from the existing adaption mechanism is necessary. As part of the RTO programme, a new adaptive algorithm is being developed, which enables all modes of transport to be modelled and optimised in a policy responsive manner. Rather than primarily focusing on vehicular traffic using traditional inductive loops, richer, multi modal data sources will be used to optimise the signalised junctions or pedestrian crossings, changing the underlying philosophy from SCOOT (of minimising vehicle delay and stops) to optimising junctions based on all road users' needs.

In general, the new adaptive control solution embraces the traditional approach, utilised in legacy systems such as SCOOT, to systematically optimise split, cycle and offset times. However, the underlying algorithms and interactions are quite different, with advanced mesoscopic simulations used to swiftly evaluate the effect of available adaption options. This increases the possibilities for effective signal time adjustments, since many more options can be evaluated with less rigid search approaches. The general strategy of the optimiser algorithms is that they evaluate changes to the input or default plan based on targeted changes based on policy and evaluation KPIs within given constraints, rather than focusing only on the degree of saturation of vehicles.

The Living Laboratory – on the Streets of London.

Whilst network simulations are useful, they do not reflect all the characteristics and dependencies of a real road network. For this reason, Siemens Mobility and TfL are deploying a "Living Laboratory" within the RTO development programme. A preliminary version of the RTO system will be deployed on TfL's network and will be used to manage traffic within a defined region in London. This real-world environment will also allow RTO and the new adaptive control features to be deployed and tested, performance improvements immediately verified and optimisation conducted if necessary.

Traffic Signal Symposium 2020

Session One

Paper Effectiveness of Bus Priority at MOVA Controlled Traffic Signals

By Sam Oldfield - WSP

EFFECTIVENESS OF BUS PRIORITY AT MOVA CONTROLLED TRAFFIC SIGNALS

Sam Oldfield – **Sam.Oldfield@wsp.com**

Introduction

The concern over the dangers of air pollution continues to increase, as does the level of encouragement for using public transport. However, local authority budgets continue to decline and their ability to provide physical infrastructure for public service vehicles has diminished. This has led to the development of technology-driven solutions that allow buses to be prioritised through traffic signal-controlled junctions.

Recent technological advances in the MOVA M8 traffic signal control system have enabled select vehicles to be specifically considered during the signal timing optimisation process. Using the modelling packages for traffic microsimulation, PTV Vissim and TRL PCMOVA3, this paper summarises an MSc research dissertation and investigates the efficacy of having a weighted degree of priority for buses over several signalled junctions. Different weighting factors have been tested using competing priority combinations, demonstrating that bus priority can lead to reduced bus journey times by up to 15.4%. It is also shown that this can lead to improvements in overall performance of the network, reducing overall delay by up to 14%, therefore, providing significant benefits to all users.

Test Sites

Due to the number of variations in junction type available, it was decided that three hypothetical junctions would be modelled in total.

Firstly, a simple two-stage operation junction was first decided upon to evaluate the effects of bus priority. Secondly, a three-stage junction with an opposed right turn movement, and thirdly, a more complex five-stage junction, utilising the 6MRR feature in MOVA.

Buses accounted for 5% of the overall traffic and detectors were placed at approximately 12 seconds cruise time away on an approach and assigned a priority MOVA detector. Each priority link was also coupled with a cancel detector to prevent any further priority actions once a bus had crossed the stop line.

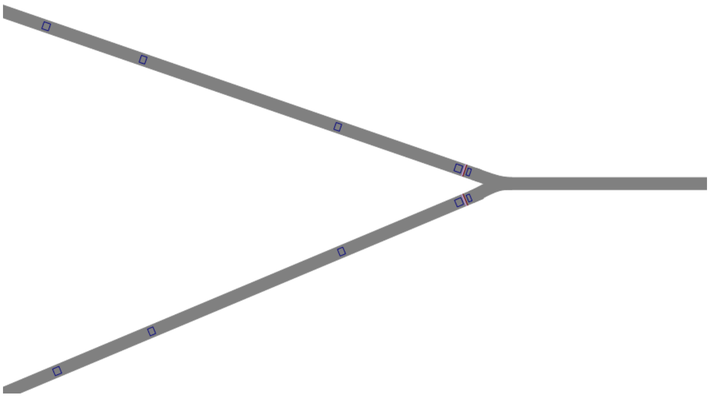


Figure 1 - Test Site 1 Vissim Model Layout

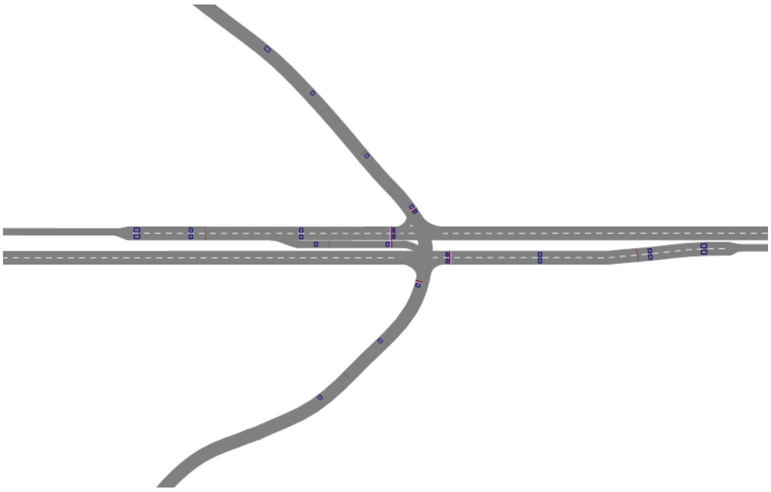


Figure 2 - Test Site 2 Vissim Model Layout

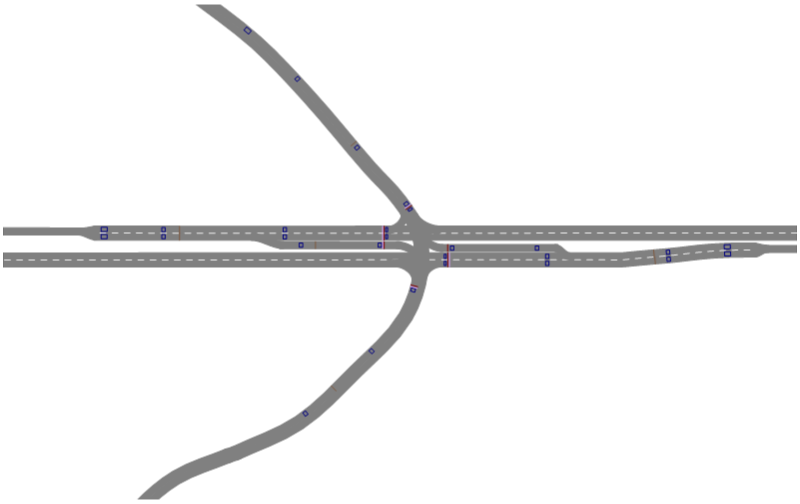


Figure 3 - Test Site 3 Vissim Model Layout

For test Sites 2 and 3, bus priority was applied to the main road approaches and the northern arm of the junctions. The following tables summarise the different scenarios of competing priority that were tested at each site.

Table 1 shows the different priority combinations tested and the number of Vissim modelling runs for Test Site 1.

Table 1 - Test Site 1 Scenario Matrix

Scenario / Bus Weighting Factor	0	2000	4000	6000	8000	10000
Priority solely on Approach A	20	20	20	20	20	20
Competing Priority on Approach A & B	20	20	20	20	20	20

Table 2 shows the different priority combinations tested and the number of Vissim modelling runs for Test Site 2.

Table 2 - Test Site 2 Scenario Matrix

Scenario / Bus Weighting Factor	0	2000	4000	6000	8000	10000
Priority on Eastbound and Westbound Approaches	20	20	20	20	20	20
Priority solely on Southbound Approach	20	20	20	20	20	20
Competing Priority on Eastbound, Westbound & Southbound Approaches	20	20	20	20	20	20

Table 3 shows the different priority combinations tested and the number of Vissim modelling runs for Test Site 3.

Table 3 - Test Site 3 Scenario Matrix

Scenario / Bus Weighting Factor	0	2000	4000	6000	8000	10000
Priority on Eastbound and Westbound Approaches	20	20	20	20	20	20
Priority solely on Southbound Approach	20	20	20	20	20	20
Competing Priority on Eastbound, Westbound & Southbound Approaches	20	20	20	20	20	20

Each model was set up to record bus journey time data on each approach to the intersection, along with network performance figures. Data was gathered in 5-minute intervals for a 90-minute model run. The 15-minute warmup and cool down periods were removed, allowing 12 time periods to be analysed per run, equating to a sample size of 240 time periods across 20 simulation runs.

To ascertain the validity of the data, each analysis set was checked with a 95% confidence interval and compared with the standard deviation. Due to the large sample set, it has been assumed that the data is normally distributed.

Results

The following tables summarise the results from each test site.

Test Site 1

Table 4 - Test Site 1 Bus Journey Time Results Summary

Bus Weighting Factor	Priority on Approach A (Approach A)		Priority on Approach A (Approach B)		Equal Priority (Approach A)		Equal Priority (Approach B)	
	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving
0	30.8		31.2		30.8		31.2	
2000	26.5	14.0%	31.4	-0.8%	26.9	12.9%	26.4	15.4%
4000	26.5	14.0%	31.4	-0.8%	26.8	13.0%	26.6	14.7%
6000	26.5	14.0%	31.4	-0.8%	26.4	14.5%	27.4	12.3%
8000	26.5	14.0%	31.4	-0.8%	26.4	14.2%	26.9	13.7%
10000	26.5	14.0%	31.4	-0.8%	26.6	13.9%	26.9	13.7%

Table 5 - Test Site 1 Network Delay Results Summary

Bus Weighting Factor	Approach A Priority		Equal Priority	
	Network Delay (s)	% Saving	Network Delay (s)	% Saving
0	2024.33		2024.332	
2000	1880.23	7.1%	1743.088	13.9%
4000	1880.23	7.1%	1765.64	12.8%
6000	1880.23	7.1%	1776.883	12.2%
8000	1880.23	7.1%	1775.64	12.3%
10000	1880.23	7.1%	1775.541	12.3%

Test Site 2

*Table 6 – Test Site 2 **Eastbound** Bus Journey Times Results Summary*

Bus Weighting Factor	Main Road Priority		Side Road Priority		Equal Priority	
	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving
0	28.0		28.0		28.0	
2000	26.0	7.2%	28.8	-2.8%	27.5	1.8%
4000	26.2	6.3%	28.7	-2.6%	26.9	4.2%
6000	26.2	6.4%	28.8	-2.8%	26.7	4.7%
8000	26.2	6.2%	28.8	-2.8%	27.3	2.5%
10000	26.2	6.2%	28.8	-2.8%	27.2	3.0%

*Table 7 - Test Site 2 **Westbound** Bus Journey Times Results Summary*

Bus Weighting Factor	Main Road Priority		Side Road Priority		Equal Priority	
	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving
0	37.2		37.2		37.2	
2000	34.2	8.0%	38.1	-2.5%	34.3	8.2%
4000	34.1	8.2%	38.2	-2.6%	35.4	4.9%
6000	34.4	7.5%	38.1	-2.6%	35.2	5.6%
8000	34.3	7.7%	38.1	-2.6%	35.7	4.2%
10000	34.3	7.7%	38.1	-2.5%	35.8	3.7%

*Table 8 - Test Site 3 **Southbound** Bus Journey Time Results Summary*

Bus Weighting Factor	Main Road Priority		Side Road Priority		Equal Priority	
	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving
0	39.4		39.4		39.4	
2000	44.0	-10.4%	39.1	0.7%	40.8	-3.6%
4000	43.8	-10.0%	39.5	-0.2%	40.4	-2.5%
6000	44.4	-11.4%	39.3	0.2%	39.9	-1.4%
8000	44.5	-11.5%	39.3	0.2%	40.2	-2.0%
10000	44.5	-11.5%	39.3	0.1%	40.0	-1.7%

*Table 9 - Test Site 2 **Network Delay** Summary Results*

Bus Weighting Factor	Main Road Priority		Side Road Priority		Equal Priority	
	Network Delay (s)	% Saving	Network Delay (s)	% Saving	Network Delay (s)	% Saving
0	4948.8		4948.81		4948.81	
2000	4867.7	1.6%	5001.27	-1.0%	4869.83	1.6%
4000	4862.9	1.7%	4986.11	-0.7%	4888.55	1.2%
6000	4861.4	1.8%	4982.92	-0.7%	4890.88	1.2%
8000	4864.9	1.7%	4983.05	-0.7%	4888.56	1.2%
10000	4864.9	1.7%	4983.66	-0.7%	4883.64	1.3%

Test Site 3

*Table 10 - Test Site 3 **Eastbound** Bus Journey Times Results Summary*

Bus Weighting Factor	Main Road Priority		Side Road Priority		Equal Priority	
	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving
0	43.1		43.1		43.1	
2000	40.4	6.5%	43.7	-1.2%	40.7	5.6%
4000	40.4	6.4%	44.2	-2.4%	41.6	3.6%
6000	40.1	7.1%	44.5	-3.0%	41.4	4.0%
8000	39.9	7.5%	44.4	-2.9%	41.8	3.0%
10000	39.9	7.5%	44.2	-2.3%	42.0	2.8%

*Table 11 - Test Site 3 **Westbound** Bus Journey Time Results Summary*

Bus Weighting Factor	Main Road Priority		Side Road Priority		Equal Priority	
	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving
0	42.5		42.5		42.5	
2000	39.5	7.0%	43.3	-1.8%	40.8	4.0%
4000	40.1	5.5%	43.1	-1.5%	40.7	4.1%
6000	39.9	6.1%	43.4	-2.2%	40.8	4.0%
8000	39.8	6.3%	43.6	-2.7%	41.3	2.7%
10000	39.8	6.3%	43.4	-2.3%	41.9	1.3%

*Table 12 - Test Site 3 **Southbound** Bus Journey Time Results Summary*

Bus Weighting Factor	Main Road Priority		Side Road Priority		Equal Priority	
	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving	Average Journey Time (s)	% Saving
0	45.9		45.9		45.9	
2000	49.0	-6.3%	45.8	0.3%	47.0	-2.3%
4000	48.8	-6.0%	43.1	6.2%	45.2	1.5%
6000	48.1	-4.6%	43.7	4.8%	46.3	-0.8%
8000	47.9	-4.2%	43.7	4.8%	46.6	-1.5%
10000	47.9	-4.2%	43.6	4.9%	45.7	0.4%

*Table 13 - Test Site 3 **Network Delay** Summary Results*

Bus Weighting Factor	Main Road Priority		Side Road Priority		Equal Priority	
	Network Delay (s)	% Saving	Network Delay (s)	% Saving	Network Delay (s)	% Saving
0	8924.9		8924.9		8924.9	
2000	8638.1	3.2%	9043.5	-1.3%	8569.9	4.0%
4000	8544.2	4.3%	9050.5	-1.4%	8731.5	2.2%
6000	8609.7	3.5%	9073.8	-1.6%	8619.2	3.4%
8000	8630.6	3.3%	9058.0	-1.5%	8816.8	1.2%
10000	8630.6	3.3%	8994.4	-0.8%	8740.5	2.1%

Discussion

Test Site 1 data showed that there were initial benefits for the use of a bus weighting factor, but subsequently there were little or no changes in travel times or junction delay when weighting increased. This was unexpected but could be due to the simplicity of the site, and in this scenario, bus priority is simply either on or off, making the weighting factor redundant. Therefore, increasing bus priority beyond the lowest weighting was not beneficial.

In addition, Test Sites 2 and 3 showed similar trends, which resulted in an initial improvement with few subsequent fluctuations in results, showing no linear correlation. This may suggest that the weighting factors used were too generous, as the lowest value tested (2000) often showed the most benefit at all sites. Also, as the weighting factor increased, there were few significant changes in the results, which may be due to random arrival patterns forming queues. It is, therefore, possible that greater benefits can be achieved by applying a weighting factor of less than 2000. The results show that this modest level of priority, however, is enough to influence the optimisation process without too much interference with the traffic model to have a negative impact. Furthermore, the findings show that disrupting internal traffic models of optimisers may have a negative impact on performance; suggesting that, as the weighting factor increases, buses are essentially given absolute priority. Additionally, Test Site 2 & 3 showed that there were advantages to bus journey times and network delays when a factor of between 4000 and 6000 was applied on the main road. Therefore, suggesting that the conditional prioritisation of buses with a high schedule deviation may lead to a higher level of punctuality, without adversely affecting junction performance.

Test Site 1 produced the most significant benefits, with bus journey times reduced by 15.4% and network delays reduced by 14%. This could be due to the simplicity of signal staging affecting the future red-time calculation and allowing the optimisation process to be extended longer; thus, increasing the likelihood that the approaching bus will pass through the already existing green signal.

Test Site 2, on the other hand, indicated that the use of bus priority solely on the side road had a negligible impact on bus journey times but caused a reduction in junction performance. This decline in performance is likely due to the MOVA algorithm itself, whereby extensions to the green on less dominant approaches actively cleared the queue on a single cycle but resulted in an increased queue length at the busier approaches. Furthermore, once the busier approaches were green, a significant amount of time was required for MOVA to detect the end of the saturation flow (to allow the optimisation process to take place), which increased the delay on the side road. Moreover, when the side road was green, the decision to end the stage was made quickly once the end of the saturation flow had been detected, without any periods of extended optimisation. It appeared that the benefit of ending the stage immediately outweighed the benefit of extending it when there were heavy conflicting traffic flows.

At Test Site 3, side road journey times decreased by approximately 6% before levelling off as the weighting factor increased. The reason for this is unclear but could be attributed to the more complex staging arrangement increasing the lost time per cycle; whereby the stops and delays optimisation process is shortened, and the side road was served quicker. However, despite improvements to the side road, the benefits were not as great as those gained by the main road traffic, which is possibly due to the speed at which the queue builds if the vehicles are stopped. As a result, the reliability of bus journey times was much more sensitive to an approach with more traffic, thus seeing the greatest benefit of prioritisation.

All three sites have shown that it is possible to reduce the overall delay in a junction by applying a weighting factor to buses. It can be inferred that this was due to several reasons; buses have a slower rate of acceleration than cars, therefore, if a bus stops at a set of signals, the following vehicles will also suffer additional delays as the bus starts to move, compared to a queue of cars only. If the bus passes through the signals, there will be less delay in the subsequent start of the vehicles. Another explanation for the overall delay reduction is the number of additional vehicles passing through the junction as the signals remain green for the bus. Either the vehicles that precede the bus will drive through the signals where they would have stopped before, or the additional group will pass through after the bus, as they further affect the optimisation process.

It should be noted that the application of the bus priority to the main road in Test Site 2 & 3 provided the greatest overall delay reduction for these sites. However, applying bus priority equally across all competing approaches produced very similar delay results, while providing travel time benefits for all approaches. The prioritisation of buses in this way will likely be far more acceptable politically than that only of the main road.

Each scenario tested shows that bus priority in MOVA is an effective way of reducing bus delays and improving overall junction performance. The costs of implementing the MOVA bus priority are likely to be negligible compared to physical infrastructure projects and should, therefore, be considered at all isolated junctions where a significant number of bus services pass through. These measures have the potential to improve air quality, increase the reliability of services and increase bus patronage.

Recommendations

Trends show that increasing the weighting factor excessively can lead to a levelling or deterioration of bus journey times and a reduction in overall junction performance. This could potentially be accounted for by noisy data, making it difficult to recommend the use of higher weighting values. However, substantial improvements can be seen when applying the equal weighting factor of 2000 over all approaches, indicating that this is a reasonable starting point for on-site implementation.

Recognising the limitations of this research, it would be prudent to further investigate different junction layouts and flow levels. This research found that there is a consistent improvement once the bus weighting factor of 2000 was applied, but the impacts of the weighting factors between 0–2000 have not yet been investigated.

Another area of further investigation is the alternative locations of SVD's and how their position may affect the optimisation process. It is assumed that increasing the distance away from the junction would lead to a further reduction in the bus delay.

A full copy of the dissertation is available upon request.

Sam Oldfield

WSP

Traffic Signal Symposium 2020

Session One

Paper Using Selective Vehicle Detection to Reduce the Impact of HGV Traffic on MOVA; does it work?

By Mark Roxburgh & Andrew Hartley - Highways England

Using Selective Vehicle Detection to Reduce the Impact of HGV Traffic on MOVA; does it work?

Introduction

Traffic signals, by design, stop traffic and create queues. This is to maximise the efficient use of the roadspace within a junction by grouping up traffic on each movement and releasing vehicles in platoons. While this stopping of traffic is necessary, not all vehicles are impacted to the same degree from having to stop; bigger and heavier vehicles lose more energy, release more brake and tyre dust and take more fuel to get going again.

In 2017 Innovation Funding was secured from Highways England's Designated Funds to undertake a trial to improve MOVA operation at isolated junctions using selective vehicle detection and priority for Heavy Goods Vehicles (HGVs). The project set out to test the following hypothesis:

> *"We can now retrofit equipment to the controller on an existing MOVA site to provide selective detection of large vehicles and thereby modify the MOVA control to reduce stops for large vehicles, improving emissions and air quality, improving junction throughput and reducing fuel consumption"*

Delivery of the project was supported by Nottinghamshire County Council, Via East Midlands, Siemens and Pell Frischmann.

The trial was delivered in the following phases:

- Pre-trial data collection surveys
- Installation, testing and commissioning of Selective Vehicle Detection
- Configuration, testing and validation of MOVA options
- Post-trial data collection surveys
- Review and analysis

A52 Stragglethorpe Road Junction

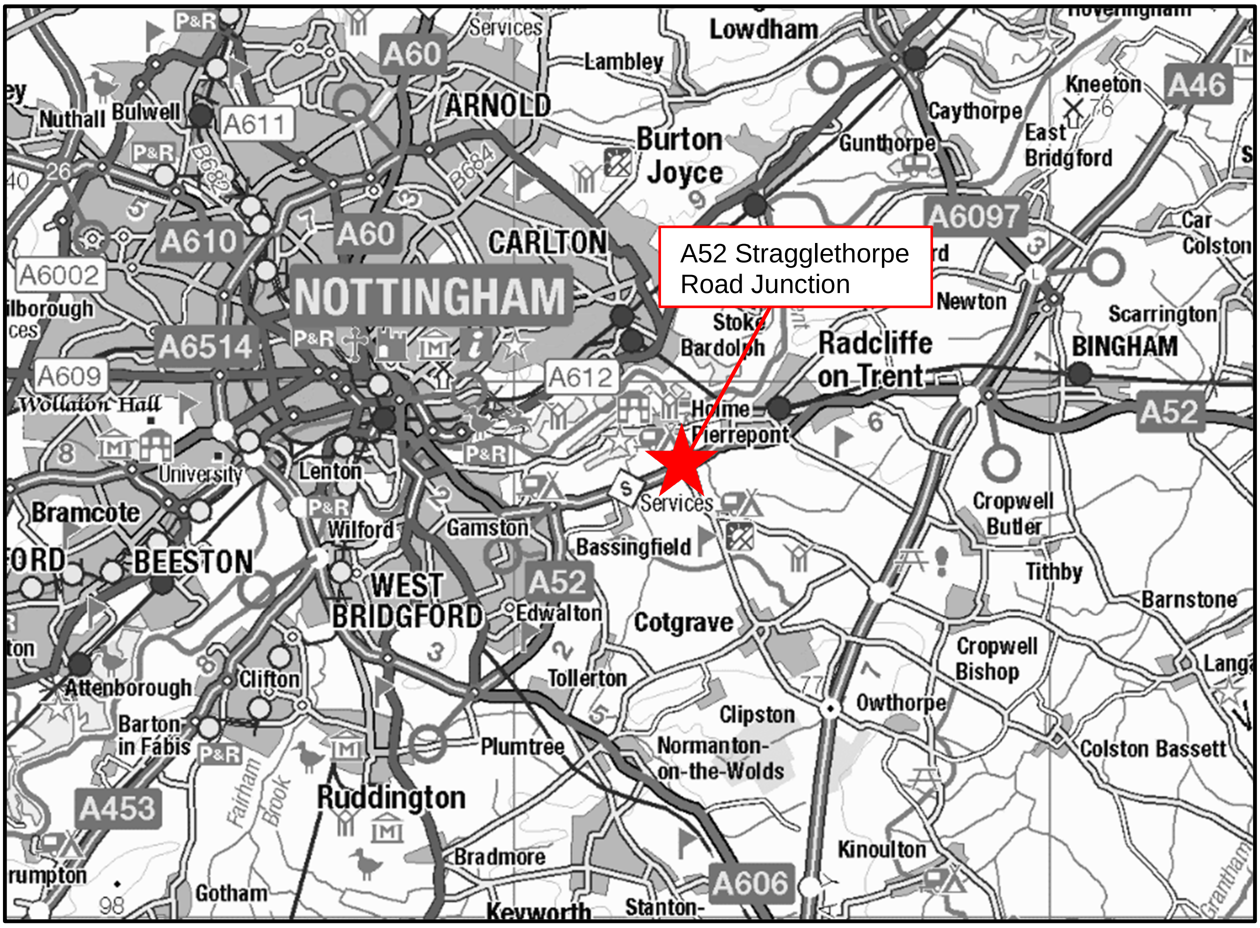


Figure 1 – Junction Location Plan

The site selected for the trial is the junction of the A52 and Stragglethorpe Road to the east of Nottingham City. There were several reasons for this site being selected:

- The site is a relatively simple 'T'-junction with no external influences on the signal control, however it does have some complexity in the MOVA control from demand dependent and alternative stages
- The approaches to the site are relatively direct with minimal flaring or need for extensive lane changing meaning there is a very good lane discipline over the MOVA loops (required for consistent profiling of vehicle types)
- The site is physically constrained with no scope within the existing highway land to widen further, though it suffers from peak time congestion
- The junction is adjacent to residential dwellings and there is an Air Quality Management Area (AQMA) designation covering said dwellings
- Due to the presence of the AQMA there is a permanent air quality monitoring site adjacent to the junction providing long term data for Nitrogen Dioxide (NO_2)
- The site has a moderate proportion of HGVs, typically around 8-10% of the daily flow on the mainline

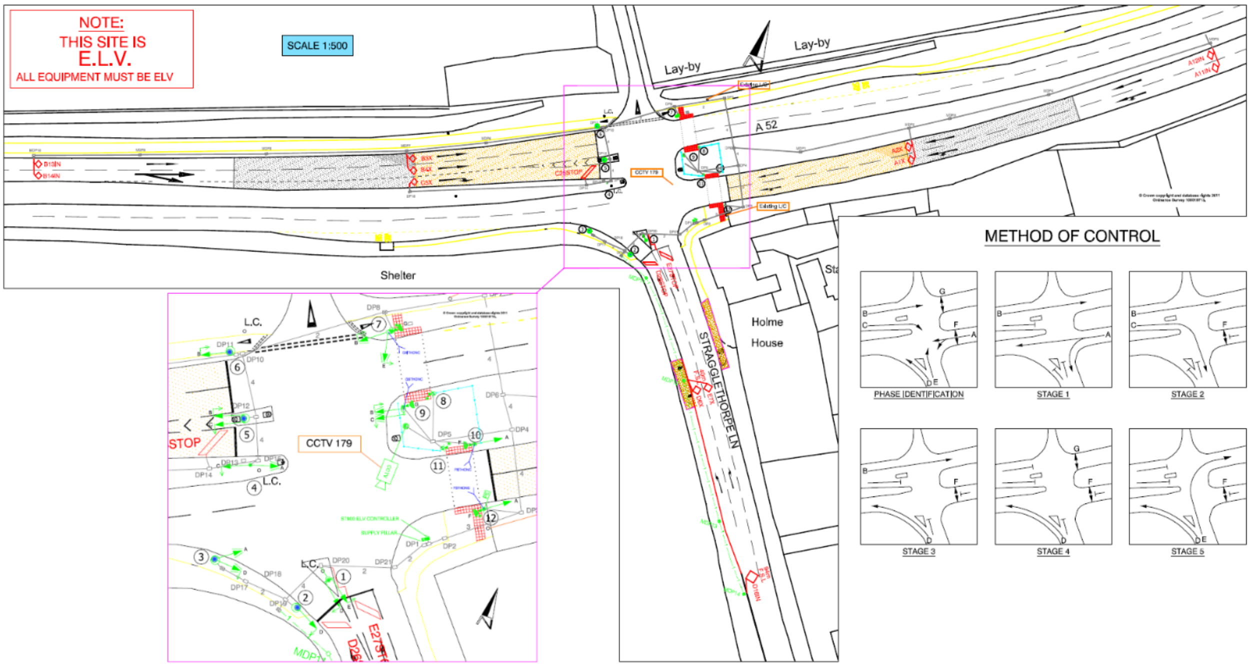


Figure 2 – Junction layout and signal control [extract from Nottinghamshire County Council drawing JH20425/06 Rev B]

The Trial

In keeping with the hypothesis, the specification for the Selective Vehicle Detection (SVD) required a solution that only involved changes to the signal controller and used the existing MOVA (diamond) detection loops. The solution provided by Siemens involved replacing the detector packs within the signal controller with the new SLD4 8+1 packs (the first time these units had been deployed in the UK). The SLD4 8+1 packs were connected directly to the existing loops and provide two outputs for each loop input; the first a traditional on/off state for the loop and the second a configurable output from the selective detection algorithm.

In this instance, the solution also required an upgrade of the controller from an ST900 to an ST950 to support the use of intelligent detector backplanes which are required for the SLD4 8+1.

The selective detection is based on assessment of the detection profile for each vehicle, with classifications assigned by matching against pre-set parameters. The units came pre-configured with these profiles; however, these were developed for square loops not diamond loops. The performance of the SVD output was commented on in the Pell Frischmann MOVA Setup and Validation report as follows:

> *"The general performance of the SVD loops was impressive, particularly given that existing traditional diamond shaped MOVA loops were being utilised rather than the more desirable and effective rectangular loop format. Whilst on site for 6 days, there were only a very small number of occasions noted when either HGV's were not detected and identified by the SVD's or smaller Luton size vans for example were classed as HGV's in error. Almost all buses were classed as HGV's but this had no negative impact and could actually be argued as beneficial."*

The design, implementation and validation of the MOVA changes was commissioned to Pell Frischmann. Three potential design solutions were developed, with each option being tested on site for two days to evaluate the impact and identify a preferred solution to fully implement for the trial. The three options are as follows:

1. Single Priority Extension – a fixed duration extension activated from detection of an HGV at the IN loop
2. Double Priority Extension – shorter fixed duration extensions activated from detection of an HGV at the X or IN loop
3. Ghost Lanes – ‘dummy’ MOVA links paired up with every normal traffic link using input only from the SVDs allowing alternative values to be used for parameters such as stop penalties

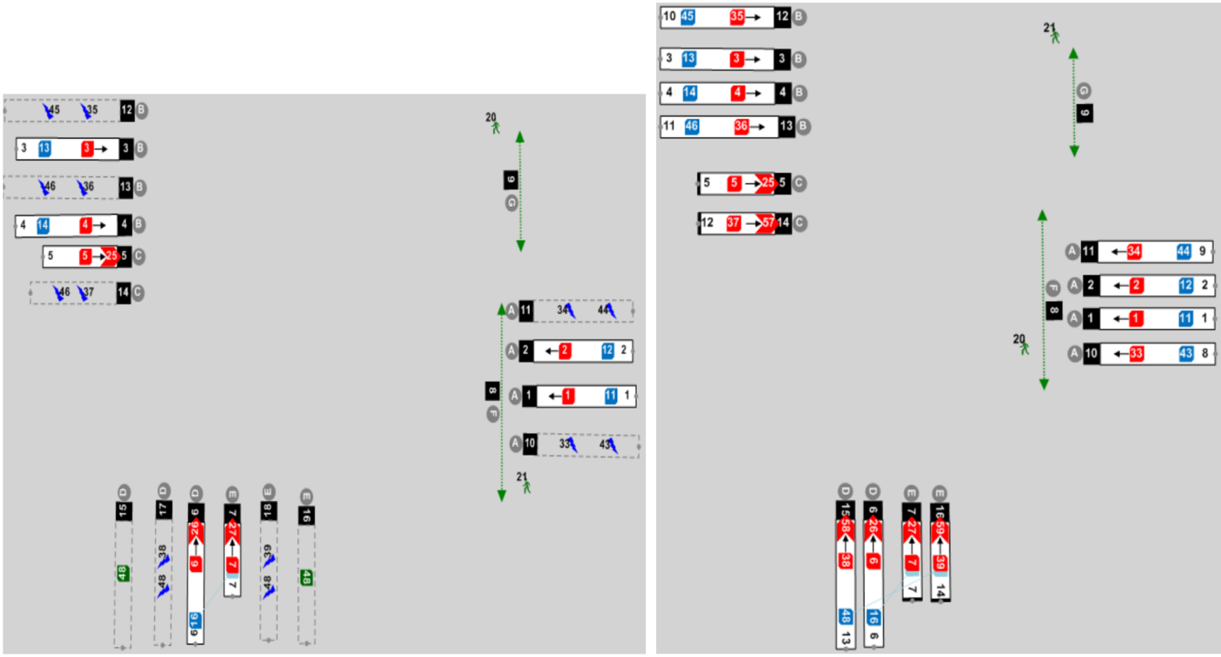


Figure 3 – MOVA Link/Lane diagrams for Options 2 (left) and 3 (right) [Option 1 not shown as nearly identical to Option 2]

Option 3 was dismissed after initial testing as this ‘soft’ approach was not observed to provide enough discernible benefit to avoiding stopping HGVs. The main reason is believed to be because of the already high stop penalty values assigned to the main MOVA links on the A52 due to the high approach speeds; this is the main parameter to influence the MOVA Benefit Dis-benefit Ratio (BDR) calculation to try and reduce the instances of MOVA changing stage in under-saturated conditions. This option also has no impact during over-saturated conditions as the low number of vehicle inputs on ghost links means they immediately find ‘end-sat’ and thus do not impact the capacity maximising mode in MOVA. The MOVA Setup and Validation report by Pell Frischmann provides further explanation of the parameters used and explanations as to their effectiveness and can be made available on request.

Both options 1 and 2 were observed to be effective at ensuring that HGVs arriving with the signals on green could clear the junction before a stage change (unless a max-change is forced). With option 1 however, it was not possible to find a suitable single extension value that ensured slightly slower moving HGVs cleared without leading to wasted green after faster HGVs.

 Author: Mark Roxburgh / Andrew Hartley 10/08/20

Hence, option 2 emerged as the preferred solution, allowing a variation in the total extension. This is because the IN loop extension is shorter (than in option 1), allowing the HGV to reach the X loop where a second extension to clear the stop-line is triggered. This set-up means that for faster HGVs the second extension is triggered earlier, reducing the total extension applied. Option 2 does not eliminate wasted green from extensions for the fastest HGVs but it does significantly reduce the frequency and extent of these occurrences.

The priority extension facility was included for all lanes at the junction for simplicity, the priority extension maximums were set at 11s for the A52 stages and 7s for the side road stages. This represents a maximum extension beyond the normal max sufficient to clear an HGV arriving at the IN loop just as the normal max green would time off.

Data Gathering

Data to evaluate the trial was gathered from several sources to understand the impact of the changes made and evaluate the hypothesis.

MOVA Logs

Data logs from the MOVA control were downloaded weekly, for a period of 8 weeks before and 6 weeks after the trial, to overlap with the traffic survey dates. For each timeperiod (the default MOVA time periods were in use on this site throughout) the MOVA logs record:

- The number of appearances and average duration of each stage
- The average occupancy for all loops on the junction
- The flow in vehicles across each X loop
- The total flow in vehicles summed for all IN loops

The logs gathered in total covered the periods of 27 June to 25 August 2017 and 13 July to 28 August 2018 (the first and last days of each period only includes data for part of the day).

Traffic Survey Data

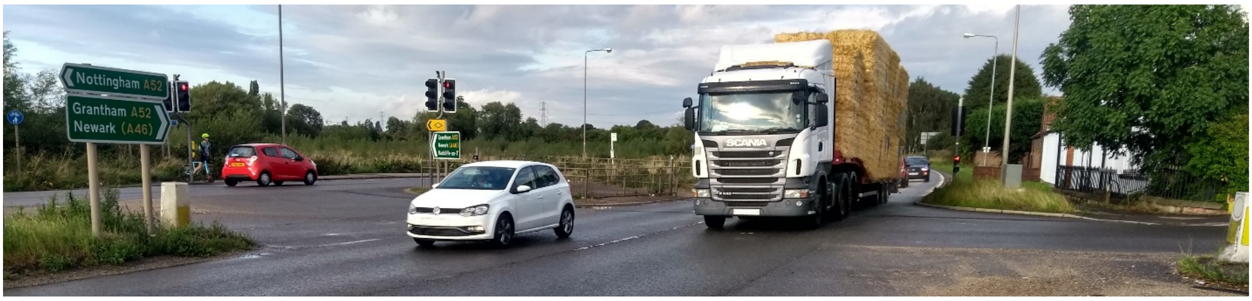
A dataset recording the number of times an HGV stopped, at what time and for how long was created by an external contractor using video footage from cameras installed at the site. This enabled the frequency and duration of stops in the pre-trial period to be compared to the post-trial period. The surveys were taken for both the eastbound and westbound carriageways for the 100m length leading up to each stop-line.

Automatic Number Plate Recognition (ANPR) data was collected for the analysis of journey time change. Several cameras set at a distance back on each arm of the junction enabled the number plate to be matched and the time taken for a vehicle to travel between the points calculated. The average time it took for vehicles to travel across the junction could then be analysed and the two periods compared to see if there were any differences in average journey time.

Automatic Traffic Counters (ATCs) were installed on each arm of the junction to count traffic during the pre-trial and post-trial periods. For each 15-minute period of each day a count of vehicles, separated by vehicle length, was recorded. Vehicle speed was also measured and a count of vehicles by speed bin was included in the data.

These surveys were carried out over the periods of 13-19 July 2017 and 9-15 July 2018.

Further investigation of the ATC data revealed some questionable outputs. The ATC data showed that overall traffic had decreased by 11% eastbound and 15% westbound, but HGV traffic had more than doubled in both directions. Verification using the video footage showed little change in HGV traffic. A possible explanation is the longer queues causing vehicles to move over the sensors more slowly, resulting in the ATCs classifying two smaller vehicles as a single HGV. In light of the issues with the 2018 ATC data, other sources were required to provide an estimate of traffic change between the periods.



Permanent Traffic Count Sites

Inductive loops in the road enable Highways England to count the volume of traffic at locations on their network. Unfortunately, the coverage of these traffic counters is patchy on some sections of the All-Purpose Trunk Road network. The nearest count site to the Stragglethorpe Road junction that has data for the pre- and post-trial periods is approximately 3 miles to the east near to the A46 Bingham Interchange. Whilst this is some distance from the trial site, in the absence of other sources it allows for an estimate of the variation in traffic to be made.

Environmental Data

Air quality data has been obtained from Rushcliffe Borough Council for the monitoring site adjacent to the trial location as well as two nearby sites at similar junctions for use as control sites. All three sites record Nitrogen Dioxide (NO_2) concentrations using diffusion tubes and at Stragglethorpe Road additionally through an automatic sensor. This data was gathered covering the periods of July 2016 to November 2017 and July 2018 to November 2019.

To support analysis of this data, meteorological data covering temperature, wind speed, precipitation cloud cover and relative humidity was obtained for the nearest available location covering the same period.

Estimated background air quality data was also obtained from the Department for Environment, Food & Rural Affairs Local Air Quality Management website for 2017, 2018 and 2019 for the 1km^2 grid covering the trial location. This data provides estimated annual average background concentrations of nitrogen oxides (NO_x), NO_2 and particulate matter (PM_{10} and $PM_{2.5}$).

Customer Survey

Three questions relating to the trial site were included in Highways England's monthly customer survey 'HighView' for January, February, March and May 2020 seeking customer views on the changes to the site and whether they had perceived any impact on journey times or frequency of stops. Unfortunately, there were only 22 responses to these questions giving a sample size that is too small to form any robust conclusions.

Results and Analysis

This section presents the key findings from the data analysis to inform the conclusions for the study, full details of the analyses is presented in separate reports.

Traffic Volumes

Doubts over the accuracy of the ATC data meant that other data sources were required to estimate the change in traffic. Sample counts were taken from the video footage. Whilst the ATC data on the day sampled suggested that westbound HGV traffic had increased by 80%, the sample counts showed a 5% increase. Eastbound HGV traffic supposedly increased by 86% on the day sampled, however, the sample counts showed a 3% reduction. It's difficult to categorise HGVs from the video footage and it's not feasible to do counts for every day, therefore these changes are only an estimation.

The Highways England data obtained from inductive loops approximately 3 miles away wasn't available for the exact dates of the trial but indicated a general change in HGV traffic of +5% westbound and +10% eastbound, which differs significantly from the video sample counts. MOVA is also a source of traffic count data, however, it doesn't distinguish by vehicle type. This data showed a reduction of 8% for westbound traffic and a reduction of 2% for eastbound traffic on the day that video sample counts were taken.

Given the limitations of the data available and the variations in results these give the change in traffic volumes cannot be reliably estimated. The best correlations in the data available indicate only small changes in the region of ±5%. The rest of the analysis assumes that there has been no substantive change in flow volumes between the before and after data.

Cycle time and Occupancy

Evidence from the MOVA data shows that the overall cycle times for the junction have increased during the trial. Increases to average stage times are evident on all four main stages (stage 4 being the exception as this is a fixed length stage for the pedestrian crossing). Increases in the stage times occur for these stages in nearly every time-period.

A review of the junction occupancy data, plotted against the total junction flow for each time interval, shows – as expected – a general trend of increasing occupancy with flow and at an increasing rate as the junction reaches capacity. Comparison of the before and after data also shows an upwards shift in the typical occupancy values, most likely due to the increased cycle times resulting in longer queues on red.

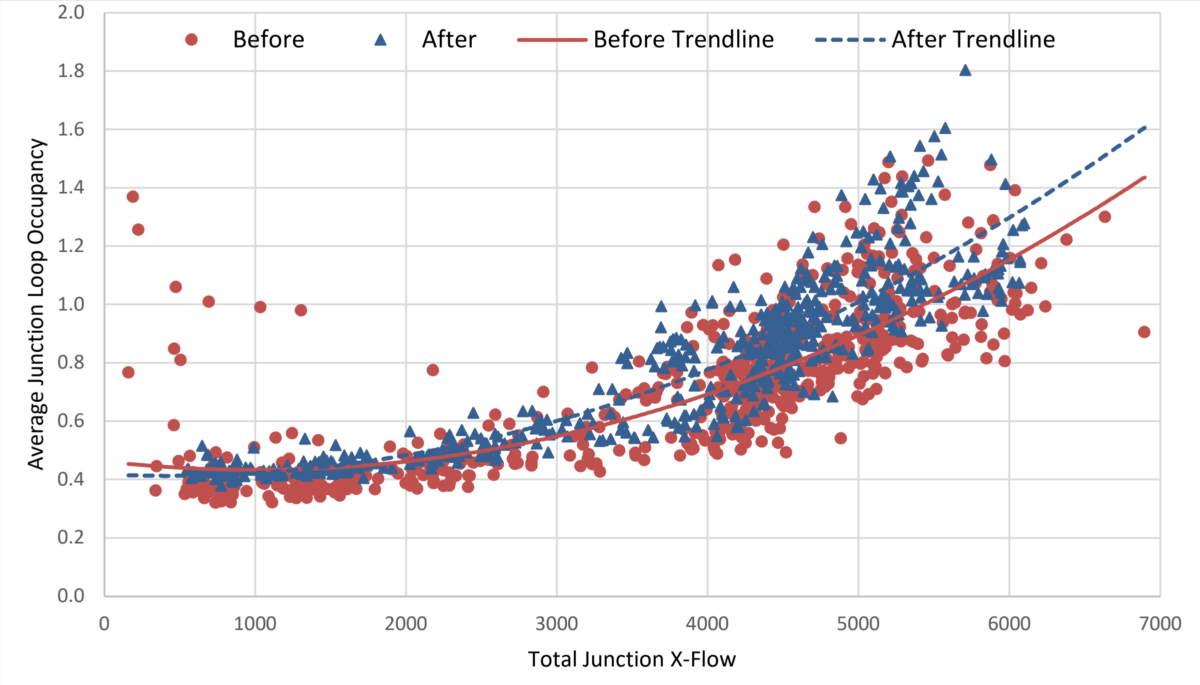


Figure 4 – Junction occupancy vs junction traffic flow, Mon-Fri

A52 Westbound Weekday

During the working week there was a significant increase in HGV stops on the westbound approach of 32%, while there were increases seen for all hours of the day these were most significant between 9am and 4pm. The average duration for an HGV stop increased slightly from 23s to 27s, however more significant increases were observed between 8-9am (25s to 50s) and between 6-7pm (22s to 46s).

Figure 5 – Total HGV stops, Mon-Fri, Westbound, by hour of the day

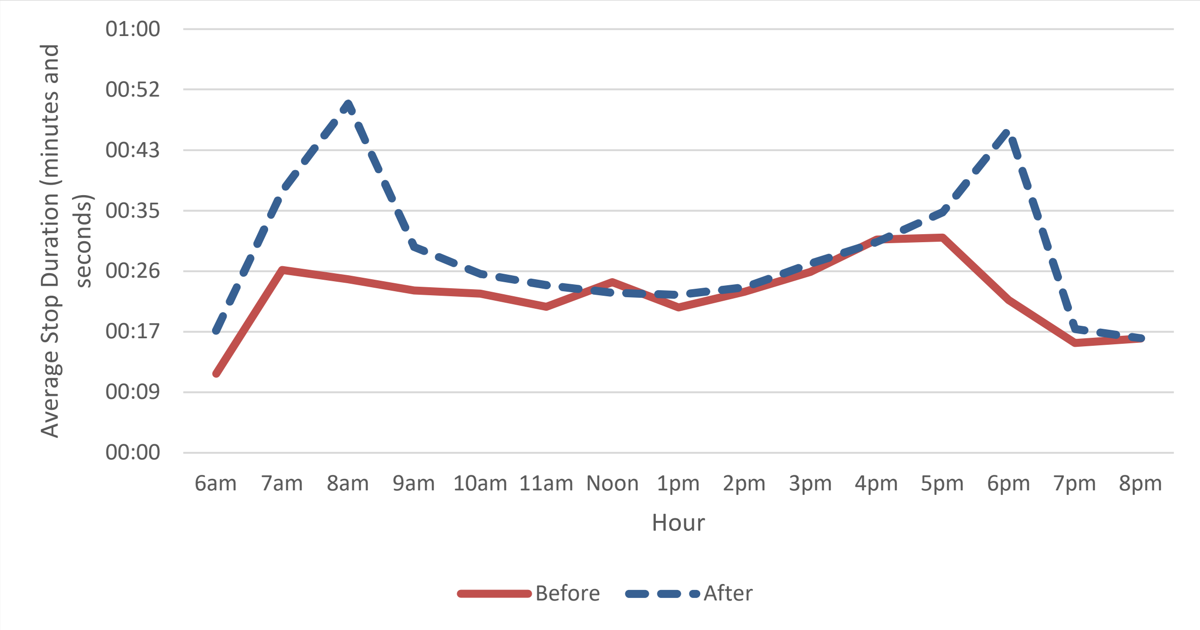


Figure 6 – Average HGV stop duration, Mon-Fri, Westbound, by hour of the day

Despite the increase in the number and duration of HGV stops, the average journey time for westbound traffic through the junction reduced by an average of 11s on weekdays during the trial.

Analysis of the MOVA data shows that there was an increase in the average duration of all four main traffic stages during the trial. For most hours of the day this change has had a greater proportional impact on the red time than on the green time on the westbound approach which is believed to be the primary cause of the increased number and duration of stops. To further note, the increased cycle time means that the demand dependent stages are skipped slightly less frequently, again disproportionately affecting the red time for the main stage.

It is also possible that roadworks at the upstream junction (A52 / Nottingham Road) during the before period was slightly gating traffic or affecting the platooning of flows arriving at the Stragglethorpe junction. This could be a slight factor in the changes seen in HGV stop frequency and delay but does not account for the level of change observed.

A52 Eastbound Ahead Weekday

In the Eastbound direction, the number of HGV stops for the ahead movement on weekdays reduced by 13% during the trial period. However, the roadworks present at the downstream junction was observed to cause queueing in the evening peak (4-5pm) back through Stragglethorpe Junction, artificially inflating the number of stops in the before data. Notwithstanding this the overall impact on HGV stops for the eastbound ahead flows is slightly positive during the day but slightly negative overnight.

The impacts on journey time and HGV stop duration overall are relatively low, with increases of 3s and 6s (excluding data from 4-5pm).

The difference in the outcomes for the Eastbound and Westbound ahead traffic is likely due to the Eastbound ahead flow receiving green in both Stage 1 and 2. As a result for the Eastbound ahead movement the increase in green time is proportionally slightly higher than the increase in red time.

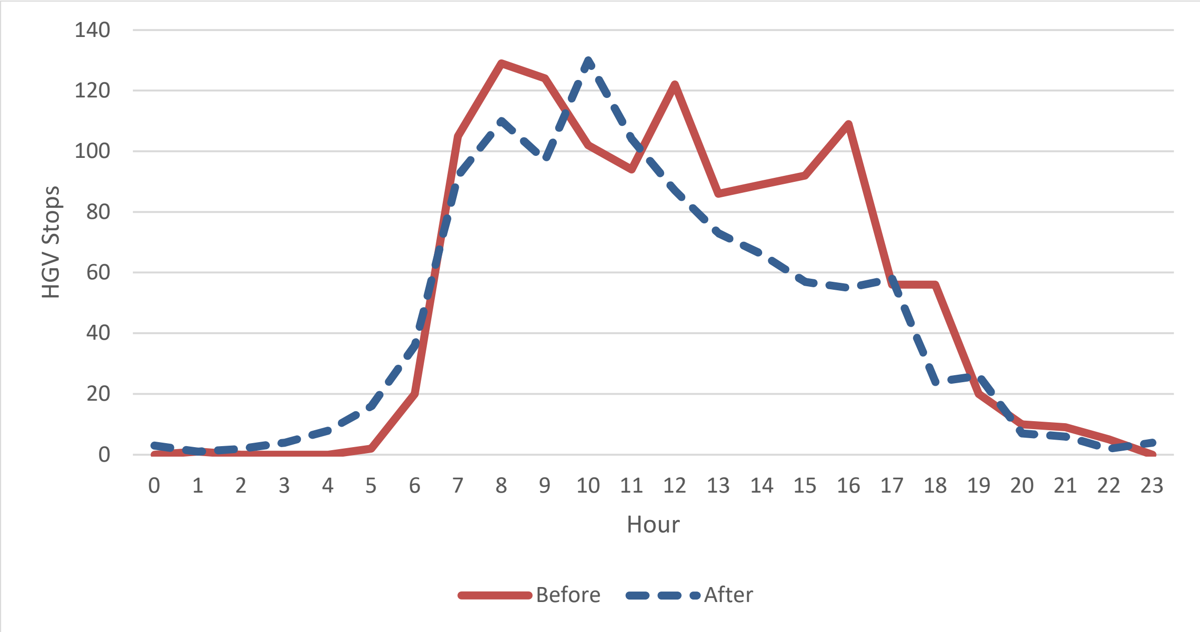


Figure 7 – Total HGV stops, Mon-Fri, Eastbound ahead, by hour of the day

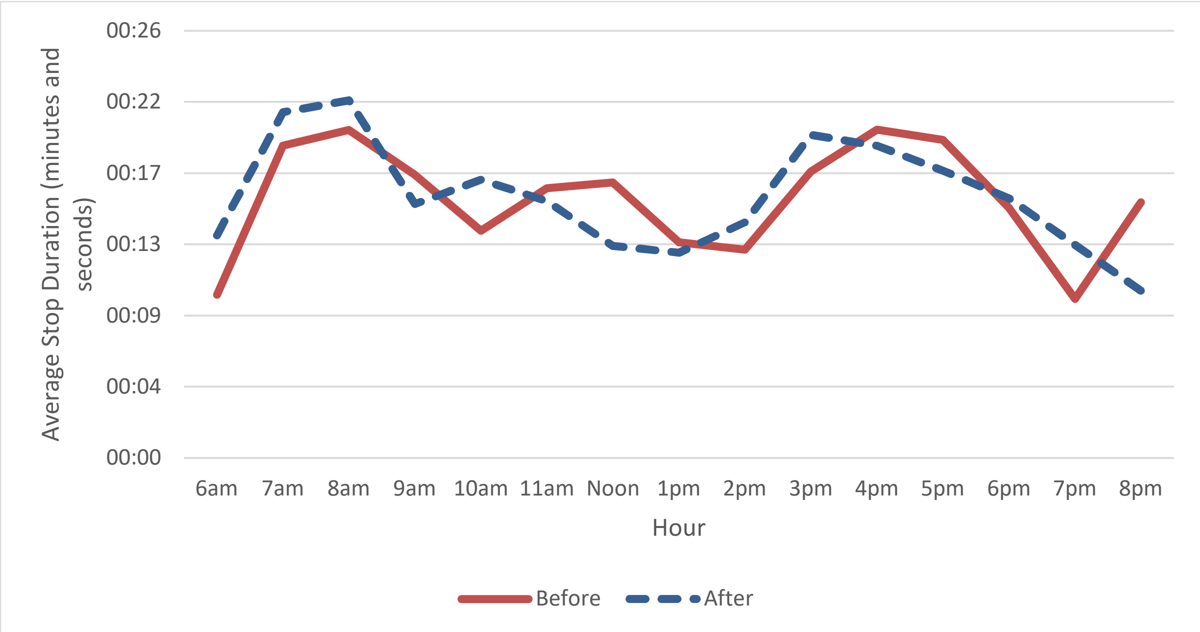


Figure 8 – Average HGV stop duration, Mon-Fri, Eastbound ahead, by hour of the day

A52 Eastbound Right-Turn Weekday

On weekdays, the number of HGV stops on the right turn into Stragglethorpe Road reduced by 9%, with the reduction largely being during the interpeak period. There was little overall change in the duration of HGV stops on this movement except during the morning and evening peaks when the average stop duration notably increased.

Looking in more detail at multiple stops, where an HGV had to stop more than once prior to clearing the junction, there was a slight increase for this right turn movement during the trial, increasing from 21 to 23. Further analysis of these events however shows that between 7-9am the number of HGVs having multiple stops increased from 8 to 16. Outside of these hours the number of multiple stops reduced from 13 to 7.

There was also an increase in the journey time for this movement of 12s during the weekdays, with the increase largely being in the morning peak, when the opposing ahead flow is highest. This data clearly shows that the longer cycle times resulted in cycles during the morning peak where the right turn movement was oversaturated and not all vehicles in the queue cleared on the first green phase.

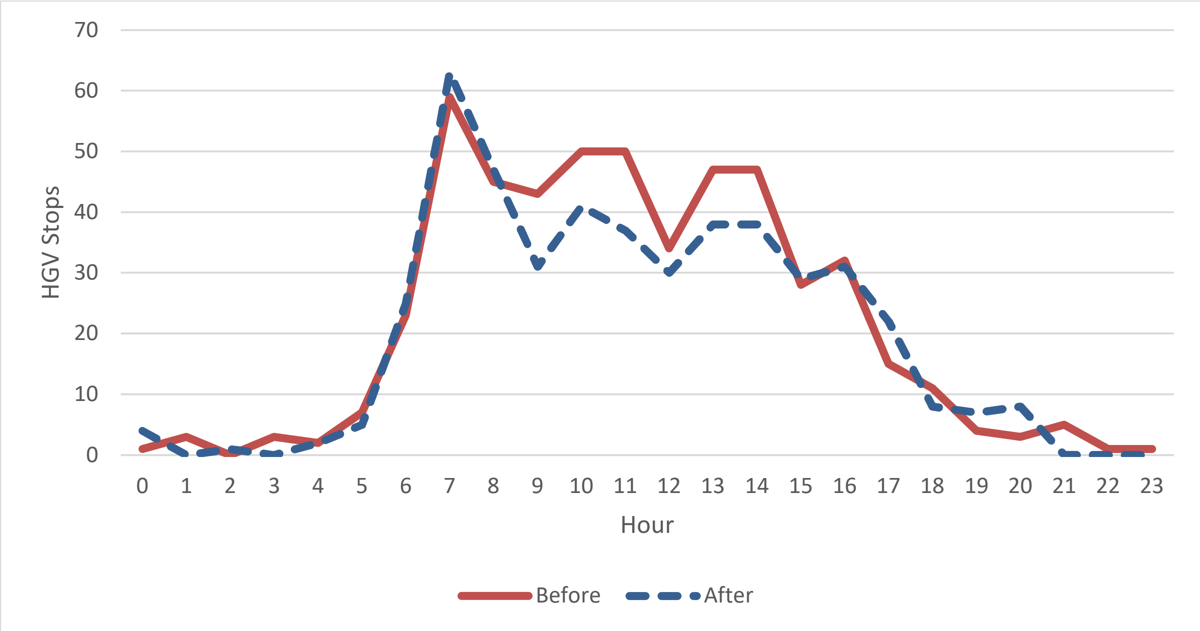


Figure 9 – Total HGV stops, Mon-Fri, Eastbound right-turn on to Stragglethorpe Road, by hour of the day

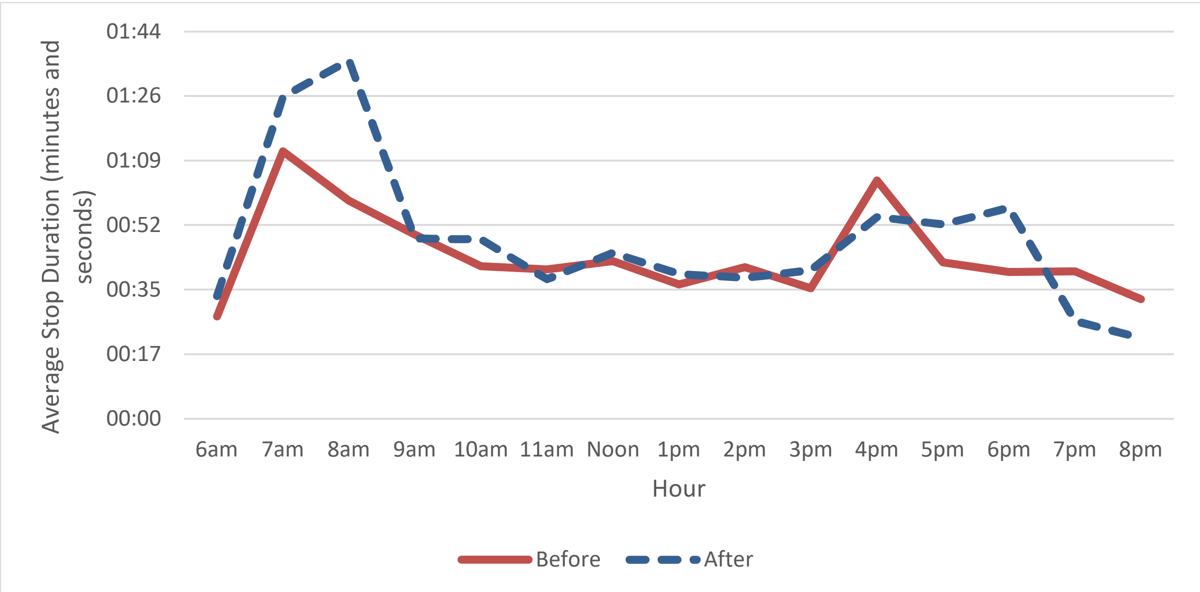


Figure 10 – Average HGV stop duration, Mon-Fri, Eastbound right turn on to Stragglethorpe Road, by hour of the day

Customer reports during the trial noted increased right turn queues for this movement, blocking back into the ahead lane during some peak periods. This is consistent with the above data and is likely linked to the increased cycle time and time on red. However, the data does also show that the priority facility here does provide a benefit in ensuring HGVs are more likely to get through when the right turn is not oversaturated.

Stragglethorpe Road Weekday

No HGV stops data was collected for Stragglethorpe Road due to the very low proportion of HGVs using this route. Weekday journey times on this approach increased during the trial with an average increase of 9s for the left turn and 3s for the right turn. This is consistent with data for the other approaches and is likely due to the longer cycle times.

It is possible that HGV stops may have reduced on this approach, consistent with the right turn in, due to the similar flow composition, turn geometry and green times.

Weekends

In the westbound direction at weekends there was an overall reduction in the number of HGV stops, reducing by 32% on Saturday and 27% on Sunday. Weekend data for the Eastbound data only covers Saturday, during which the number of HGV stops on the ahead movement reduced by 39% during the trial. Similarly, the number of stops for HGVs making the right turn into Stragglethorpe Road on Saturday reduced by 30%.

The improved performance during weekend is likely linked to the reduced HGV proportions in the overall flow.

Air Quality Impact

The NO_2 data from the monitoring site adjacent to the trial shows a slight reduction in concentrations during the trial when compared to the before data. However, similar reductions are also evident in the control sites as well as in the estimated annual average concentrations.

As such it can be concluded that the trial has had no measurable impact, positive or negative, on the concentrations of harmful NO_x concentrations. It is also probable that there has been either a neutral or slight increase in particulate matter concentrations due to the increase in the frequency of HGV stops.

Evaluating the Hypothesis

The starting hypothesis can be broken down into a few elements which can be evaluated individually to inform the overall evaluation.

We can now retrofit equipment to the controller on an existing MOVA site to provide selective detection of large vehicles

The installation of the Selective Vehicle Detection (SVD) at this site was undertaken without the need for any traffic management, although the increased sensitivity of the system did highlight that one of the loops was failing and needed to be re-cut under normal maintenance processes.

This trial has clearly shown that SVD can be readily retrofitted to existing MOVA sites, at least where lane discipline over the loops is good. There are also several other sites known to have installed similar systems, although typically using rectangular loops – either existing or new.

There is still scope for the technology to be developed, particularly in terms of the software and configuration to improve reliability when using diamond loops.

Thereby modify the MOVA control

This was already known to be true from previous implementations of SVD systems. This trial looked at two alternative methods (fixed priority extensions and dummy 'HGV only' links) of using the SVD input to alter the behaviour of MOVA both of which worked to differing degrees.

To reduce stops for large vehicles

Overall the data shows that the effect of the trial has been to increase the number of HGV stops, even accounting for a slight increase in HGV numbers. However, there is also evidence of benefit on the right turn movement from the A52 into Stragglethorpe Road.

Observations on site confirmed that the changes were ensuring that the SVD input was extending the green phase to allow HGVs to clear where otherwise MOVA would be likely to end green, thus preventing that HGV from having to stop. This is supported by the clear increase in average stage times showing that the revised control strategy was consistently extending beyond the previous MOVA control setup. While these extensions have allowed the vehicle on green to clear, the resulting red time increase on competing approaches has resulted overall in more HGV stops.

The net result is that the previous operation of MOVA was giving a better balance, maintaining overall junction efficiency, at the cost of occasionally stopping HGVs approaching on green. Conversely, the blanket approach taken has removed the ability of MOVA to take a more wholistic view, extending green for as little as one HGV without any regard to the traffic build up on other approaches.

Despite the disappointing overall result, the reductions in HGV stops seen in the right turn movement from the A52 into Stragglethorpe Road does prove that such systems can provide a benefit. The key difference with the right turn movement is that large vehicles slow down more than small vehicles when approaching the junction turn due to the tight radius. This creates a gap in the platoon which MOVA will often see as inefficient and instigate a stage change. Over time this becomes self-reinforcing as regular users, bus drivers for example, expect not to clear on the current green if too far back in the queue and thus accelerate even more slowly resulting in larger gaps.

As the platoon is then not cleared, MOVA is almost immediately presented with a fresh demand for the right turn stage, encouraging shorter greens on other stages to cycle round and subsequently a worse saturation flow on the next green as the heavy vehicle is at the front of the platoon.

Notably in the case of this site, there is a bus stop a short way into the side road and if a bus is at the front of a platoon of right turning vehicles and makes a stop, the rest of the platoon queues back into the junction creating further adverse effects.

Improving emissions and air quality

The environmental data obtained did not show any clearly identifiable change in local air quality resulting from the trial. This is particularly noteworthy as the movement with the largest impact on stops, albeit negative, is the one closest to the monitoring station.

We know that an HGV stopping and starting results in greater tail pipe emissions as well as generating particulate matter from brakes and tyre friction, however, even with the measurable increase in the number of stops, the net impact was shown to be too small to detect within the wider variations.

Thus, while the link between HGV stops and air quality is known and proven, the level of impact that is likely to be achieved from an HGV priority system at an individual junction is too small to be claimed as an air quality scheme. Implementation over a wider area, such as an urban network with multiple signal sites, may provide greater benefits, however, this needs further research to evidence.

Improving junction throughput

There is no evidence from the study evaluation that the junction throughput has increased due to the trial. The longer cycle times may have indirectly improved the capacity; however, the extended greens result from prioritising HGVs clearing the junction after the main platoons have cleared potentially resulting in a loss of efficiency.

The general trend of increased journey times on most movements evidences an overall reduction in efficiency, most likely due to the priority extensions overriding the optimisations within MOVA.

Reducing fuel consumption

Overall the trial has been shown to increase stops and journey times, likely leading to a slight increase rather than decrease in fuel consumption. However, if the dis-benefits can be designed out and the benefits identified to the right turn movement retained then it is probable that this would lead to a slight overall improvement in fuel consumption.

Summary and Conclusions

The trial has shown that selective vehicle detection of HGVs can be used to provide a benefit in MOVA control, however, it is not universally beneficial and careful thought is required when implementing it.

The greatest benefits have been gained on movements where there is a clear speed differential between large and small vehicles, for example on a tight turn radius. In these cases, MOVA may tend to make a stage change due to a gap in the platoon which it assumes to be an inefficiency. The use of selective detection can override this where the gap is caused by a large vehicle moving slowly and ensure that the signals are kept green to allow the vehicle to clear and not be stopped at the front of the platoon.

On more free-flowing movements or on phases with generally high green times the use of a priority extension from selective detection of HGVs may be less efficient than allowing the junction to cycle. Evidence from the trial shows clearly that, even with a relatively simple (5-stage) junction these holds result in a net detriment to the junction operation.

In such cases, use of the softer ghost links approach will allow MOVA to continue to optimise but nudge the optimiser towards allowing the HGV to clear. As such, where traffic is built up on other approaches MOVA will not look to extend but will extend if traffic is much lighter. Such an approach however is not likely to effect significant changes where stop penalty values are already high.

The benefits of such an approach however are relatively small and the trial has not been able to provide sufficient data to clearly evidence the magnitude of benefits due to the dis-benefits also present. Prior to any future implementation it is recommended that further desktop analysis or traffic modelling is undertaken to evaluate the value for money case.

At Stragglethorpe Road a future scheme to ban the U-turn movement and overlap stages 2 and 3 is now planned. As such an immediate change has been initiated to remove all the priority links except the one on the right turn from the A52 into Stragglethorpe Road. A further review looking to implement priority extensions for traffic approaching on Stragglethorpe Road and ghost links for the A52 ahead movements is proposed to be included in the forthcoming scheme.

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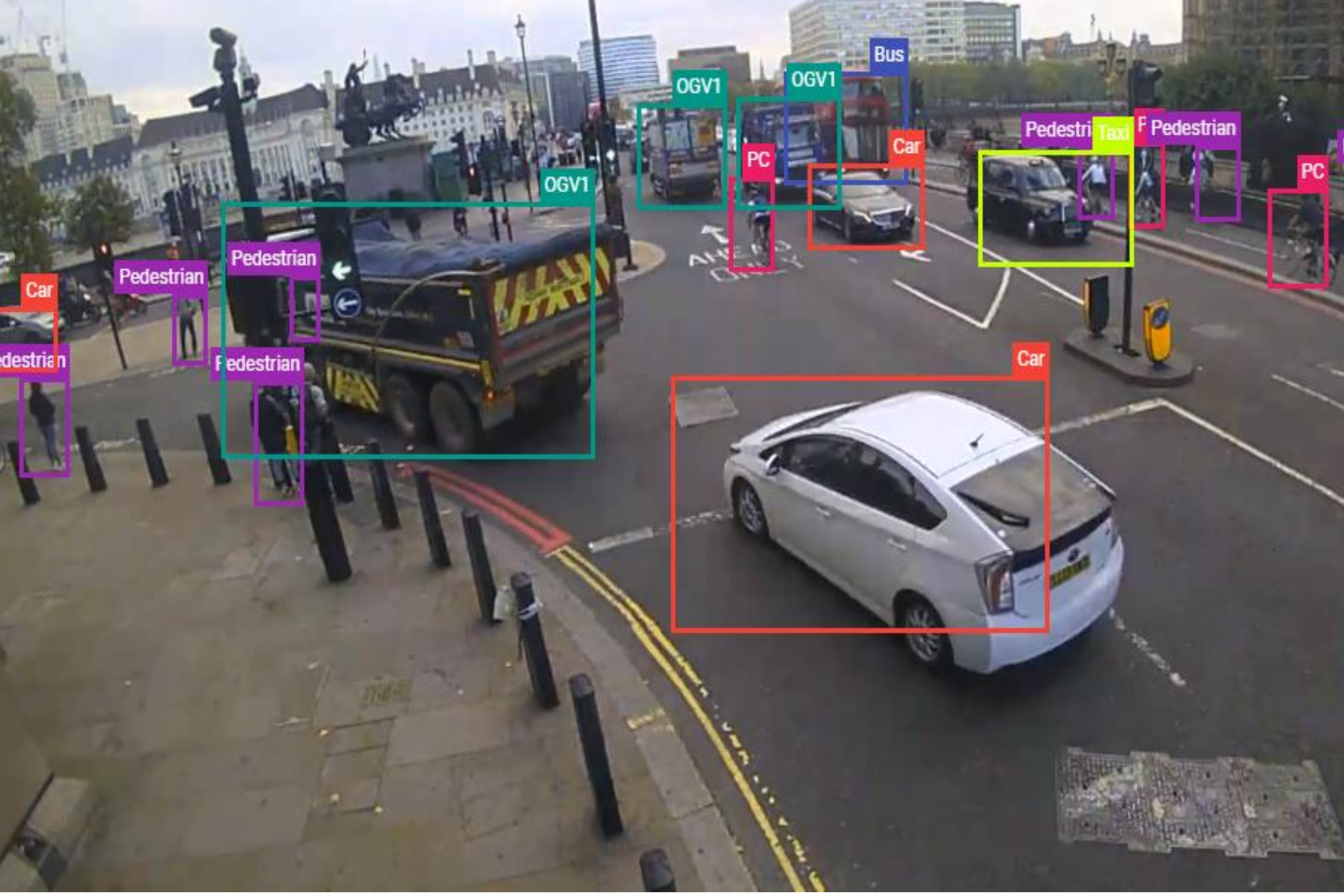
Traffic Signal Symposium 2020

Session Two

Paper AI to control traffic signals: Lessons from live deployments in Manchester

By Raquel Velasco- Vivacity Labs & David Watts TfGM



Smart Junctions

Transforming Traffic in Greater Manchester with Artificial Intelligence

1. Executive Summary

Smart Junctions is a 3-year, Innovate UK co-funded programme exploring how Artificial Intelligence can be used to improve traffic signal control. This programme will result in a rollout across a region of circa 20 signal-controlled junctions in Greater Manchester, ultimately targeting a new paradigm for signal control. The key objectives are:

- **Multi-modal optimisation**, using sensors able to detect 9 road user classes
- **Fully automated calibration,** eliminating costly calibration and validation cycles
- **Dynamic optimisation**, adapting to coordinated or single-junction control, and to live random events such as lane closure

Vivacity Labs have partnered with Transport for Greater Manchester (TfGM) and Immense Simulations to use AI to optimise traffic networks. The new system will give transport authorities unprecedented ability to efficiently implement new strategies such as:

a) Focus on **promoting active travel** by prioritising cyclists and pedestrians, thereby improving journey quality and safety

b) Prioritising **air quality** by reducing the amount of breaking, accelerating, and idling of high-emissions vehicles

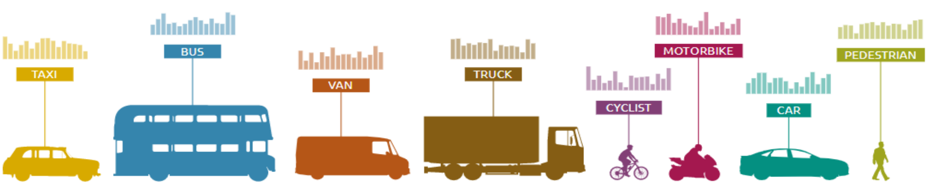
Authorities will be able to seamlessly shift between strategies in different areas or times of the day to suit their needs and priorities; for example, a focus on **congestion reduction** along main arteries during peak commuting hours, active travel during the weekend, and air quality in off-peak periods.

In the second year of our 3-year programme, we have achieved the following key milestones:

- The **first live trial on Thursday, January 30th, 2020**; successfully controlled the traffic signals at a junction using Artificial Intelligence.
- Continuing to control trial junction, expanding hours of control to include morning and evening peaks
- Initial results saw an improvement on average delays at this junction during the first control.
- **Controlled a total of three junctions independently by July 2020**

Over the coming year, we will:

- Simultaneously control **three junctions over the next month** ahead of the JCT symposium
- Extend the focus on pedestrians and cyclists, expanding to junctions along **Deansgate, an area with high pedestrian traffic**
- Demonstrate coordination and impact in the real world in the form of improved journey quality for all road users in this region.
- Scale up to an area of 20 junctions in Manchester by the end of 2021



To our knowledge, this is the first application of Reinforcement Learning in traffic signal control in the UK, with one of the largest, real-world trials of its kind world-wide.
In this paper we are going to present the journey from test bench prototype to real world trial, giving further details about the solution that has been successfully implemented in Greater Manchester.

This is a continuation of last year's paper and presentation titled "Artificial Intelligence for Signal Control - working towards rollout in Greater Manchester" in which we presented the solution and early research results.

2. Project overview and Year 1 Recap

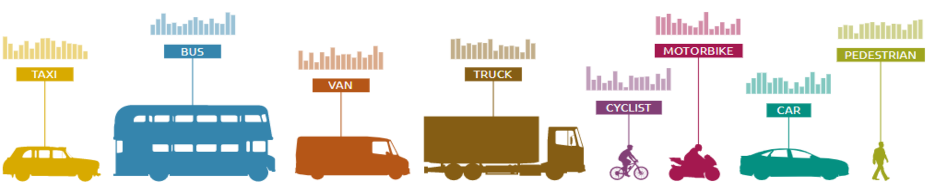
Challenges with existing solutions

Many transport authorities are trying to move beyond simply reducing traffic congestion. Optimising air quality and prioritising active travel and public transport reliability are now critical to transport policies. SCOOT and MOVA have dominated traffic signal control in the UK for the last decades and while both have scenarios in which they work effectively, reducing congestion through coordination of multiple junctions (SCOOT) or through adaptively clearing queues and growing cycle times (MOVA), they have both struggled to implement air quality or multi-modal optimisation effectively.

Air quality optimisation with SCOOT has been trialled, but not rolled out at any scale. Bus priority in SCOOT, while well established, is a relatively blunt instrument, overriding optimisation for any other mode to provide late buses with green lights, and thus degrading overall system performance. Meaningful prioritisation for other key modes, such as cyclists, is not widely available. Meanwhile, it is well known that performance of SCOOT degrades over time, often by up to 30% - but recalibration is manual and expensive and often not viable for many authorities.

Vivacity Smart Junctions Solution

At Vivacity, we are addressing all of these issues. Vivacity is using cutting-edge Reinforcement Learning, a branch of machine learning, to develop an algorithm which is able to adapt quickly to changing traffic conditions and efficiently implement high-level strategies at both local and city-wide scales. The system takes full advantage of the unique capabilities of Vivacity's existing sensors to detect and classify 9 different types of road users. This accurate, real-time multi-modal data makes it possible for the algorithm to prioritise different modes of travel, thereby giving councils the unprecedented tools to effectively prioritise active travel, public transportation, and air quality. Crucially, we can also optimise for congestion - allowing transport authorities to choose a balance of prioritisation between air quality, particular transport modes, or underlying congestion. Finally, AI has the potential to self-calibrate, maintaining performance indefinitely as the system self-improves and retrains following changes in the network.



A year ago:

At last year's JCT we presented our idea of applying artificial intelligence to traffic signal control and described why AI and, more specifically, reinforcement learning are well suited to traffic problems. One year ago, we had successfully completed a test bench demonstration of the system working and, perhaps more importantly, proving we had designed and created a safety-critical system. After this key milestone, we were ready for real world trials. The key new work presented in this paper is therefore the deployment in the real world, and scaling towards controlling 3 junctions simultaneously.

3. Reinforcement Learning Research

Reinforcement learning (RL) is an optimisation technique of learning from experience. The RL algorithm or "agent" begins by choosing random traffic stages, and then by using the inputs from the Vivacity sensors (such as positions, speeds, and waiting times of different road users), it can see what the traffic looked like before and after each stage. This way, the agent can learn how 'good' it is to make each decision in a given situation. Over many iterations the system can, therefore, improve itself and choose the best stage at any point in time, to optimise performance according to a council's priorities.

To allow the system to safely make poor decisions as it begins this learning process, we have worked closely with Immense Simulations to build accurate and fast microsimulations. The overall workflow of commissioning a smart junction is shown in Figure 1, and a still image of the simulation can be seen in Figure 2. The dataset available from the sensors has made it cost-effective and scalable to do this very accurately, by automating significant portions of this process. We've now run over 8 million simulated hours to train the system: the equivalent of observing and controlling a junction for a millennium!

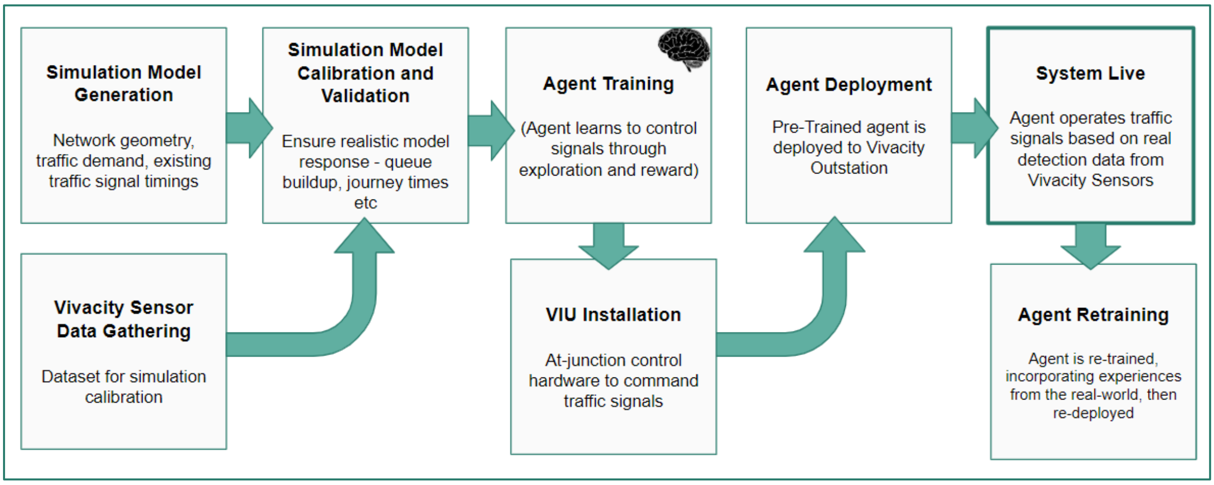


***Figure 1**: Overall workflow towards a trained and deployed reinforcement learning system for traffic signal control*

Figure 2: Simulation of a junction in Salford in 3D environment

Reinforcement learning (RL) as a field has a history of learning advanced skills and even innovating new strategies. For example, Google Deepmind recently developed an RL system which reached the top league of StarCraft 2; a game which involves very quick and complex coordination amongst multiple decision-makers. We are using similar approaches to optimise and coordinate across traffic signals, where several deep machine learning models learn and interact in a structured manner to collectively optimise the overall performance of the system.

Once the system has been trained in simulation, we evaluate its performance in simulation through a series of tests. Again, by leveraging automation we're able to do this at a very large scale, resulting in distributions of performance which are more reliable than an individual simulation. For each training run of the system, we examine its performance across a range of demand levels, and for each demand level we evaluate the system against up to 100 scenarios, allowing a robust comparison of performance envelopes with benchmark systems.

One simple benchmark system we've compared with in simulation is vehicle actuated (VA), or System D. We have seen a 22% reduction of waiting time for vehicles and pedestrians for a typical week, based on observed demand levels at the first trial junction in Salford. The improvement is biggest during high demand, and a simple average across the demand levels tested results in an improvement of 34%. Figure 3 shows how this improvement is distributed across demand levels for both the RL system and VA.

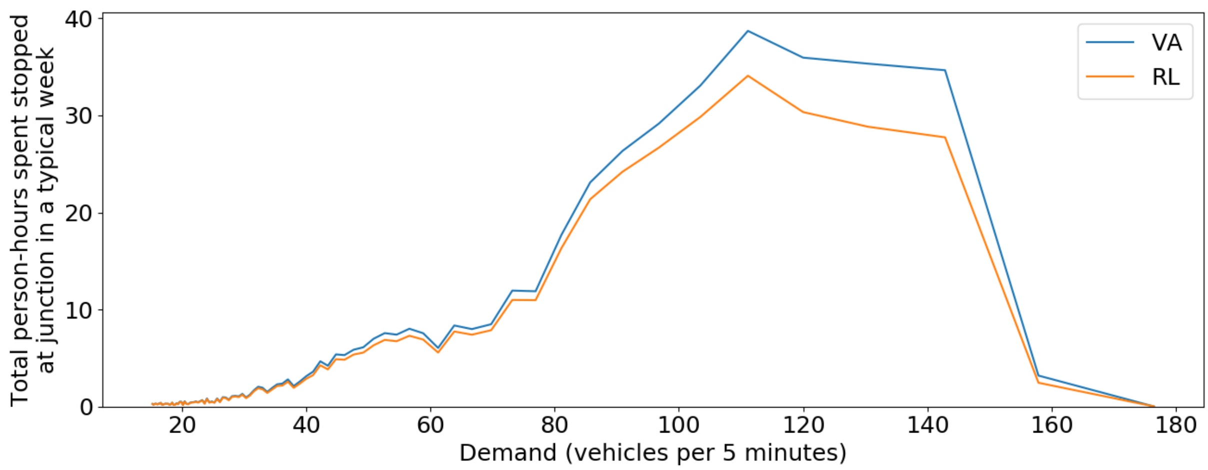
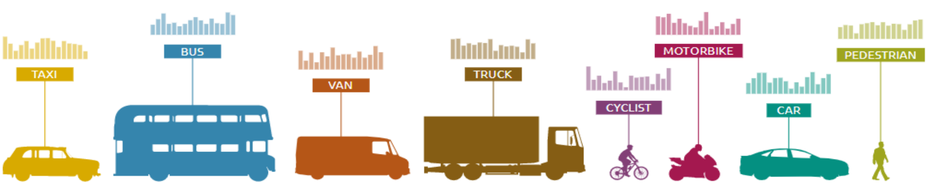


Figure 3: Simulated comparison of total time spent stopped per week under VA vs RL



4. Path to real world control

The first phase of the project focused on building an offline test bench system (shown in Figure 4) to demonstrate core functionality and system safety. We developed a custom outstation: the Vivacity Intelligence Unit (VIU), which is installed in the controller cabinet and interfaces with the traffic signal controller.

The VIU contains a powerful GPU-based compute unit which receives live data from nearby Vivacity sensors, hosts the RL control agent, and issues requests (force bits) to the controller, as well as streaming data to our cloud-based monitoring systems.

We worked with TfGM to design the system architecture and VIU itself which were engineered according to various real-world requirements, constraints, and assumptions:

- The Vivacity system shall revert control to legacy system as required (TfGM)
- Failures of prototype system shall not cause safety hazard to signal operation
- The system shall be able to be integrated with standard signal control system
- Assumed local network required for low latency sensor to VIU comms

***Figure 4**: The test bench included 14 sensors. a Siemens controller with a modified configuration (not pictured) and the VIU installed in the same cabinet*

The test bench demonstrated:

- **A functioning system:** Agent taking action based on observed demand from the sensors and the VIU sending commands to the controller
- **Constraints obeyed**: The system served pedestrian stage within a certain time of the ped button being pressed
- **Controller hierarchy obeyed:** Controller only obeyed commands from the system when an SF bit is set to TRUE

Once this system safety and core functionality was proven on the test bench, we could shift focus towards real-world deployment. We worked closely with TfGM to select the initial pilot site and subsequent trial region in the Salford region of Greater Manchester which can be seen in Figure 5 below.

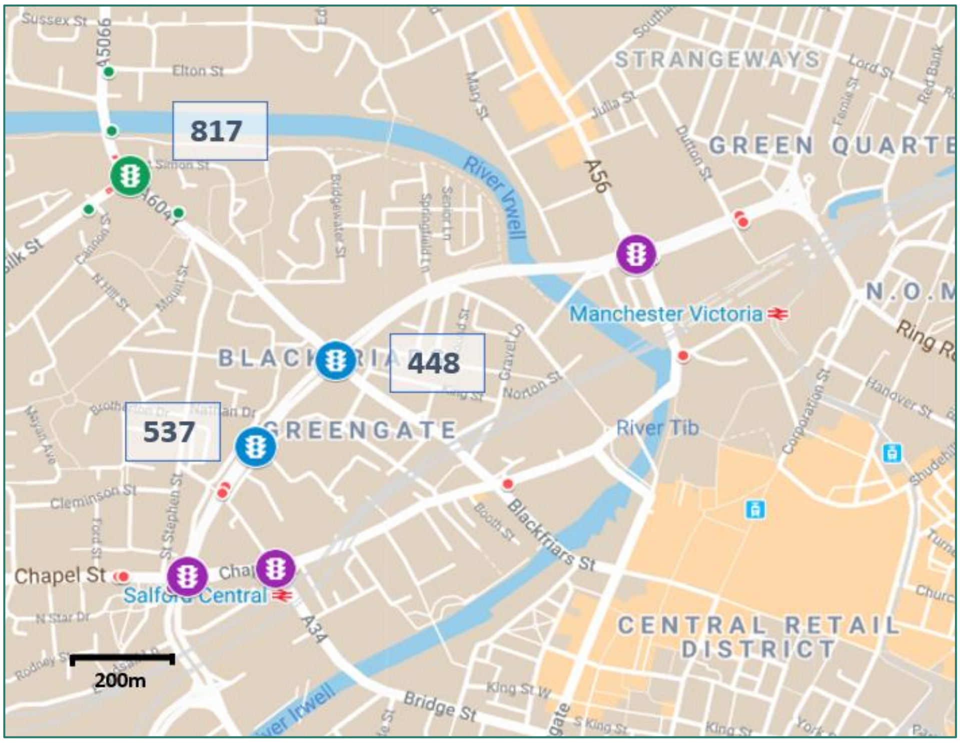
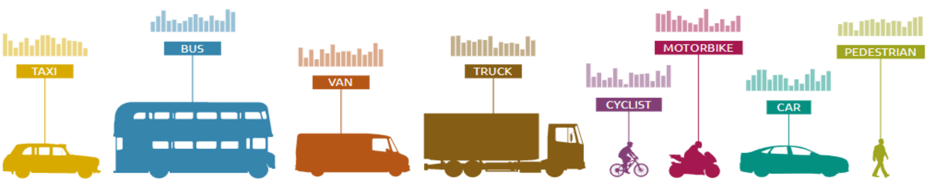


Figure 5: *Initial trial region in Salford. The traffic light symbols represent the junctions we will be controlling this year and the small dots are the sensors that are currently installed in and around the junctions. First pilot site (junction 817) in green, next two junctions (448 and 537) in blue and subsequent three junctions in purple.*

5. First Control with AI

The first pilot site was junction 817, the intersection of Blackfriars Road and Silk St. This junction has four stages and is currently under SCOOT control and was last re-validated on 19/12/2016. Figure 6 below is an aerial view of the junction and stage diagram.

Figure 6: *Junction 817, the first pilot site, with representative occupancy zones and stage diagram*



In order to commission the whole system at the first pilot site, and to ensure all core system components were functioning as intended, we employed a staged approach. We gradually increased the complexity of the control algorithm controlling the traffic signals:

1. **Fixed time:** A simple, fixed time algorithm that did not rely on sensor data, but running on the Vivacity system. This proved that the VIU system was fundamentally stable and capable of controlling the traffic signals.
2. **Max occupancy:** This algorithm brought in real-time detection data from the Vivacity sensors and closed the control loop around queue lengths. This deterministic algorithm works to simply serve the stage with the highest demand, as measured by the vehicle "occupancy" of notional queuing zones on the approaches to the junction. The algorithm also employs some backstop constraints to avoid undesirable bad traffic outcomes, such as always ensuring that pedestrian demands are served within a given time, and that all stages are at least served even if their demand is generally low.
3. **RL agent:** The first live trial of the full AI system; **successfully controlled the traffic signals at the pilot junction using Artificial Intelligence on Thursday, January 30th, 2020** from 10:00 to 14:00.

Performance of first deployment

Initial analysis on the performance of the algorithm in the real world saw a reduction of average delays when compared to the performance of the existing system at this first trial junction. Qualitatively, the agent displayed generally sensible behaviour with well-timed stage closing when queues were cleared and longer stage times when queues were longer. Pedestrians were served promptly and the much busier Blackfriars Road got overall higher priority than Silk Street. We also observed some less than ideal behaviour, such as stage 4 not being served quickly enough when only one car was queuing, or pedestrians served too eagerly when clearing a platoon of vehicles would have been a better option. These shortcomings were used to further refine the RL agent, as described below.

Continuing to iterate

After this initial control we continued to control the junction periodically, extending the hours that we were in control into the shoulder periods. Throughout these deployments we improved the system in the following ways:

- **Completely remote deployments:** The first control was done with the team physically onsite. Subsequently we improved the control monitoring interface to allow us to make updates to the system and control the traffic junction remotely, facilitating more frequent control.
- **Algorithm performance improvements**: continuing RL research, we introduced new agents that each performed markedly better than the previous in simulation. Figure 7 shows the performance improvement on average waiting time in simulation of each agent that was used on junction 817.
- **New behaviour tests**: During training of the RL agents, we incorporated certain behaviour unit tests where there is a known "right" answer, for example only a single vehicle waiting.

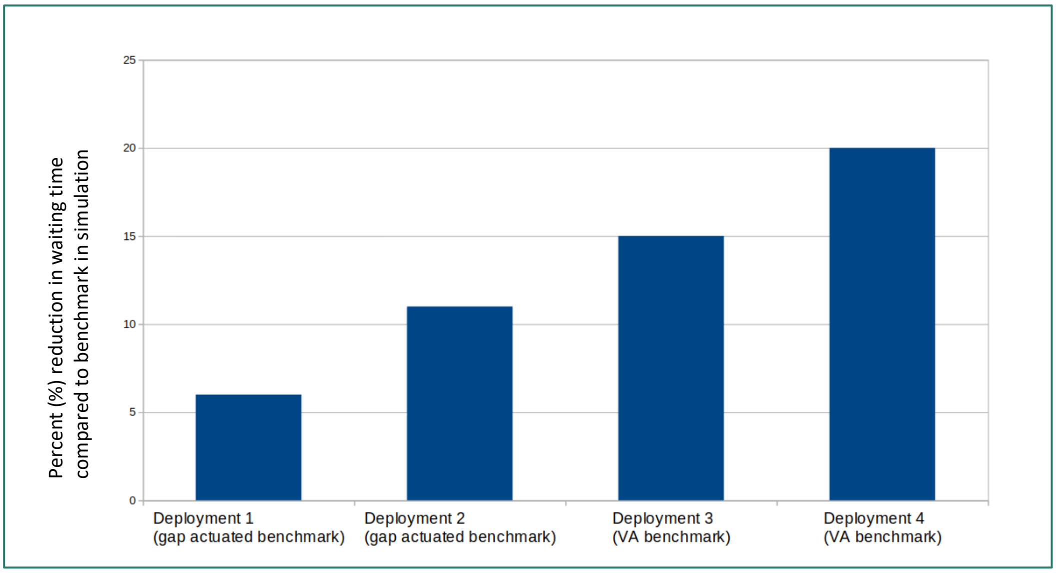


***Figure 7**: Comparison of the first 4 agents we deployed in the real world. This is their performance in simulation compared to the baseline algorithm (gap actuated and then vehicle actuated).*

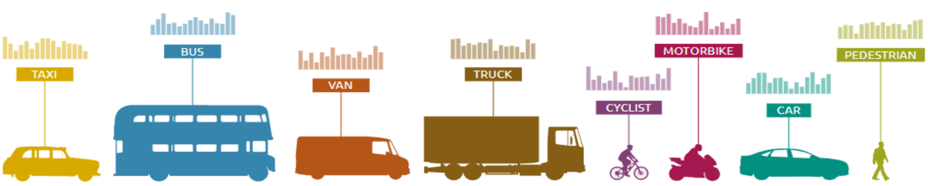
Unfortunately doing a robust performance analysis on these subsequent deployments and getting a like-for-like real world performance comparisons are currently not possible due to the current pandemic and nationwide lockdown which have severely impacted traffic conditions across the country. Therefore, ongoing performance analysis of the system is being conducted as traffic conditions continue to change.

6. Towards multi-junction control

With consistent, safe control of junction 817, we set our sights on to the next big milestone: multi-junction control. After an 18-month journey to controlling the first junction, we controlled the second junction (junction 537) 5 months later in July 2020. Then, the third junction, 448, just 2 weeks after that.

Scaling to new junctions required a new calibrated simulation model of this larger region as well as improvements to the software stack to generalise it for new junctions. On the research side, bigger junctions and the challenge of coordination has introduced new complexity. We are exploring different approaches to multi-junction and coordinated control, such as comparing the performance of individual agents at each junction versus one global agent controlling an entire region.

This research has already yielded promising results in simulation and we have started to see emergent coordination of the traffic signals. Three agents working side-by-side to control three neighbouring junctions in simulation has produced a 49% reduction in waiting times for vehicles compared to VA. While this is a strong start, this result is not unexpected since VA is not optimised for coordination between nearby junctions. Going forward, we are further developing the benchmarking suite to be able to robustly compare the system's performance against industry standard algorithms.



7. What is next?

Simultaneous control

Having already controlled three junctions independently, we are going to be simultaneously controlling all three junctions in early September this year, ahead of the JCT Symposium. Similarly, to the approach during the trial junction, we are taking learnings from these initial controls and improving the agents ahead of simultaneous control. During this next phase we will be looking to gather more real-world performance data in order to demonstrate real world performance improvements such as journey time reductions, as well as working towards better coordination across this three-junction region.

Large-region control

Over the coming year we will continue to scale and expand into larger control regions. More than 50 sensors are already in place on and around a 7-junction area (Figure 5) and we are currently installing sensors on 6 more junctions along Deansgate in Manchester, a heavily pedestrianised area. As we scale, we will be continuing research into regional coordinated control and also exploring multi-modal optimisation further. The expansion into Deansgate will give us an excellent opportunity to this, particularly as this is a region that does not currently use adaptive control.

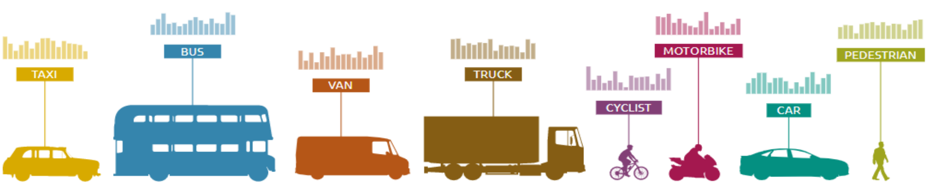
Expand functionality in the Vivacity Dashboard

We have already begun to incorporate real-time monitoring features into the Vivacity Dashboard, our UI product for data visualisation. We've worked closely with TfGM and other authorities to design new features and over the coming year, we are looking to expand this functionality to create a user interface for junction and control monitoring. The current "junction view" shows the active stage as well as control and reply bits and we will be adding additional real-time data.

8. How do we believe this will compare to MOVA and SCOOT?

We will be looking to achieve a number of key benefits vs MOVA and SCOOT:

- **Ability to do more with less:** We are looking to address the budget cuts and skills shortages that many councils and authorities have faced in recent years by creating a system that allows transport engineers to spend less time handling the minutiae of the current, immediate problems and more time thinking about policy and transportation strategy.
- **Dynamic shifting between coordination and individual junction optimisation:** Instead of having to choose between MOVA and SCOOT, or trying to deploy time-based variants, the AI will learn when to coordinate junctions, and when to control them independently. There will be no strict concept of a SCOOT region, but Reinforcement Learning allows us to avoid the concept of a strict region through more adaptive junction groupings, in a much more flexible manner than existing multi-control-algorithm approaches.

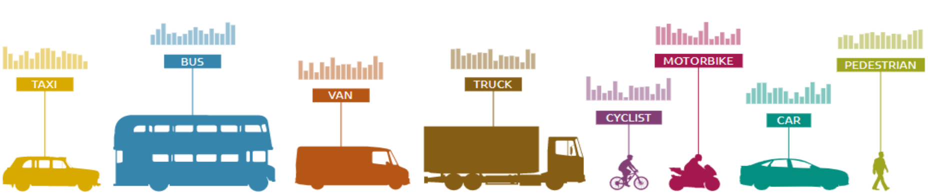


- **Auto-calibration:** Machine learning systems, by definition, improve with experience. Junctions will not need lengthy initial manual calibration periods at installation; signal control algorithm calibration can be executed automatically and continuously through a combination of simulation and real-world learning.
- **Modal and Air Quality Optimisation:** The AI can learn for a variety of different optimisation goals. We have high-quality modal data already from the sensors, and can prioritise cyclist or bus journey times at will. If appropriate, we can also prioritise air quality, such as by training the AI using a proxy such as acceleration profiles or number of stops.
- **Rapid Response to changing environments:** Today, if a lane is closed or when a football match finishes, existing algorithms struggle to adapt appropriately, and typically need timetabled or manual intervention. However, by including these scenarios within the training set, we can give the AI the opportunity to experiment with different solutions and embed that into the AI's memory, ensuring that the system automatically puts in place the right response to these scenarios when they occur in the real world.

9. How can I find out more?

We will be running a User Group for transport authorities on Tuesday, October 13th, aiming to discuss our work in more detail and explore some of your objections and challenges to deployment. To find out more, or to request an invitation for the User Group, please get in touch with your regular Business Development or Customer Success Manager or reach out to Raquel at Raquel.velasco@vivacitylabs.com .

Similarly, if you would like to talk to us about providing further test and demonstration sites, or would like to request more information about our sensors, please get in touch.



Traffic Signal Symposium 2020

Session Two

Paper Reimaging Traffic Control and Management for Network Sustainability.

By Professor Margaret Bell- Newcastle University

Reimaging Traffic Control and Management for Network Sustainability.

Professor Margaret Bell CBE

Future Mobility Group,

School of Engineering,

Newcastle University.

A note from the Author:

"This paper as it is presented here does not constitute a publication it is a draft to stimulate discussion and to invite feedback prior to future publication. In what format (journal publication, chapter or book) will depend on whether the content proves to be useful.

Any feedback or correction is welcomed."

Reimaging Traffic Control and Management for Network Sustainability.

Professor Margaret Bell CBE
Future Mobility Group,
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ABSTRACT
This paper will look back at the beginnings of fixed-time area control of networks, plan change algorithms and benefits of co-ordination. The early attempts at developing demand responsive control systems at a time when detector technology was insufficiently robust and computers far too slow will be briefly explained. The basics of the fully demand responsive control system SCOOT, Split Cycle Offset Optimisation Technique Hunt et al (1981) will be explained and the need for research into the ageing of traffic signal plans being necessary to enable Local Authorities to justify expenditure on the state of art technology in the mid -1980s. However, despite increased sophistication in technology, within a decade increased car ownership, their use and for longer journeys, meant that traffic congestion remained a problem with the unintended consequence of poor air quality which remains a concern. Examples of traffic management measures to manage hotspots, and Air Quality Management Areas will be proposed and evidence that electric vehicles will not deliver the mandatory 67% reduction of carbon dioxide emissions target by 2050 over 2010 levels will be presented. The potential to use data available as by product of UTMC, Urban Traffic Management and Control to identify the level of traffic in a network which potentially will meet environmental objectives will be explored. Finally, ideas of how traffic control and management can help to reimagine and reengineer our networks in the future will be shared.

Introduction
In the late 1950s and early 1960s as cars became more affordable at peak times traffic in side roads began to suffer unacceptable delay. This prompted research into the design for isolated signal control the basic principles of which can be found in the seminal work of Webster and Cobbe (1966). These calculations were initially carried out manually. However, at a time when Government policies were creating a pro-car society by the mid-1960s as more and more junctions became signalised travelling through urban networks was frustrated by the need to continually stop at each junction. This led to the concept of signal co-ordination which initially was introduced predominantly along radials into a town or city. The starts of green at consecutive junctions were shifted – or offset - by the time taken of travel between the two junctions. The travel time was based on the desired/designed cruise speed and the stop-line to stop-line distance between consecutive junctions. This allowed green waves to be created for the dominant flows into or out of city. Early work (by Morgan and Little) (1964) considered methods which minimised band-width.

However, these early signal control strategies were often unable to provide sufficient bandwidth to allow green waves to be created for traffic flowing in opposing directions and often created long delays on side roads at junctions with high cross flows. Several methods of achieving linking were explored and are dealt with in the Webster and Cobb (1966), these include simultaneous or synchronised system, alternative or limited progressive system, flexible progressive system.

Signal design calculations were carried out manually and time distance diagrams used to create the linking. However, as computers became affordable software was written to facilitate these calculations and algorithms were developed to achieve the linking. Of note is LINSIG, Moore and Cheng (2004) developed in the 1980s by Brian Simmonite as a DOS based tool whilst working at Lincolnshire Council and later set up JCT to support others who found the valuable time saving tool. Whilst setting up green waves removed the stop – start issues traffic growth meant that delays increased on side roads as traffic queued to gain access to main roads.

At the time Dr Dennis Robertson working at Plessey (now Siemens) was developing the signal optimisation program, TRaffic Network StudY Tool (TRANSYT). He later moved to the Transport and Road Research Laboratory (TRRL), where UK government investment led to the software tool being adopted throughout the UK, Robertson (1969). TRANSYT has proved to be one of the most successful software tools developed, Holroyd and Hillier (1969), Timmermans et al (1979) and quickly TRANSYT was adopted by many authorities worldwide.

TRANSYT Traffic Model
TRANSYT manipulates flow profiles with NO representation of individual vehicles. The flow distribution during the cycle time refered to as the *flow profile* is assumed to be the same every cycle throughout the plan.

Traffic Flow Profiles
The pocessing of vehicle flows through a TRANSYT networkRobertson (1974) is based on manipulation of three patterns:

a) IN pattern which represents the arrivals at the stop line at the end of the link if the traffic were not impeded by the signal at the stop line,
b) OUT pattern which leaves the link and
c) GO pattern which would leave the stop-line if there was sufficient traffic to saturate the green.

The traffic flowing into the link is obtained by taking the correct proportion of the OUT pattern from the upstream link. The traffic entering the link is dispersed assuming exponential smoothing. The amount of smoothing depends on the journey time. Calculations are performed on an averaged picture but in practice the flow pattern varies because of the behaviour of the individual vehicles therefore, this random behaviour is accommodated with a correction factor.

Queue length, delay and stops
TRANSYT has a simplified model for vehicles travelling down a link. It assumes that all vehicles in the platoon travel at the same speed and arrive concurrently at the downstream stop-line in this way a **vertical queue** is formed at the stop-line. The average queue is estimated from the IN, GO + OUT patterns. When the saturation flow S< 100% average queue is equivalent to the rate which delay is incurred and when S>100% average arrivals > departures. Work by Bell (1978, 1981) studied 500 traffic queueing at signalised junctions and derived the unit of queue for a PCU, passenger car unit was 5.76±0.05 metres. Bell used this to develop an enhanced spatial queueing model and incorporated inot TRANSYT.

The **uniform delay** is defined by the cyclic flow profile which is the elapsed time from arrival at the stop-line to the departure in the green. The random delay is established by an empirically derived formula and is about half the random delay of traffic at an isolated junction as defined by Webster and Cobbe (1966). All traffic delayed contributes to stops even without stopping, given the assumption of vertical queues. The to the stop-line and accelartion away from the verticle queue is solved by fractional stops. Additional stops, caused by random variations and oversaturation are added to the "average picture".

The random plus oversaturation delay rate is equivalent to average pcu's in the queue at start of red. If it is assumed that all such pcus stop each time signals become red then:
Stops /pcu = $(N_{\text{start red}} - N_{\text{departures}})$
This is equivalent to the average number of red periods which each pcu must wait before crossing the stop line, which is equivalent to (random + oversaturation) stops/pcu. An arbitrary upper limit is set as 2 stops/pcu.

TRANSYT Performance Index, TPI
The TRANSYT derives signal times to benefit traffic across a whole netowrk and achieves this by minimising an Performance Index. The TRANSYT Perfomance Index, TPI, see Equation 1 minimises delay and stops and manages queues on short links.

TPI = U delay + R+O delay + U stops + R+O stops + queueing measure …….Equation 1

Where U is Uniform, R is random and O is oversaturation

The TPI can be translated into money cost and/fuel consumption using empirically derived relationships. TRANSYT minimises the TPI using a HILLCLIMBING PROCESS (which is a misnomer because the optimal solution is when the TPI is at a minimum) to either optimise signal offsets and/or splits. The green period of one junction is related to another via the **master cycle.** A **stage change time** at a junction is a time at which the green signal on one stage is terminated and the change to the next green period is initiated (next stage green commences following inter-green period). The **offset** is the stage change time when the change to green for stage I is initiated (ie start of cycle for node concerned). Subtracting the offset node (1) from adjacent node (2) gives the journey time. This difference in offset which gives start of the cycle of one node relative to another defines co-ordination. Over the intervening years TRANSYT has been extensively developed to improve its optimisation procedure and provide many facilities which:

a) catered for up to 7 signal stages at each of up to 50 junctions and 250 approaches
b) allowed for rigorous checking of data input and graphical display of flow profiles.
c) calculated initial signal settings by a method of equalising saturation.
d) modelled traffic sharing at a stop-line and in bottleneck situations.
e) gave priority to buses
f) accommodated signalised pedestrian crossings

Bell (1981) using the more realistic queuing model for TRANSYT Bell (1978) introduced the concept of a performance measure which included a component of spare capacity to enable offsets to be defined which prevented queue-back on traffic links.

Definition of signal plans

Some links in a network will experience little variation in flow throughout the day, whilst others will exhibit dramatic changes. It is the flow profiles of the latter type that should be used toidentify how many plans should be implemented, and when to change from one plan to the next. A technique often used to ascertain the time schedule for implementation of a set of plans is to overlay the daily flow profiles established for traffic at the crtical junctions in the network. Figure 1 is an example of a daily flow profile measured at a critical junction along a radial at the edge of an UTC system.

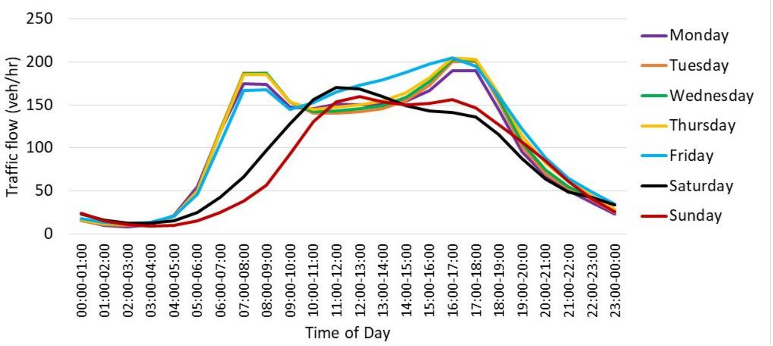

Figure 1. Average Daily Traffic flows

The different profiles shown here were based on twelve months data captured by automatic detectors but given the technology available in the early 1980s such profiles often would be based on one days measurement on a day of the week considered representative of all days often chosen as a Thursday. Traffic counts would be made, sometimes manually, on the one day of the week at approximately 6 monthly intervals over a period of typically two years. These daily flow profiles presented in Figure 1. for each week day suggest the need for a morning peak plan between about 07:30 and 09:30 hours, off peak 09:30 to 16:00 evening peak 16:00 to 19:00, after which vehicle actuation would be operated. Different plans and durations would be implemented on weekend days. When delays were found to be significant at other times spending resources to create special event plans to manage football matches, trooping of the colour in London and wet and dry weather plans in coastal towns to cope with tourists heading to the beach in fine weather can be justified.

When and how to change plan

Of course, due to random variations, the traffic flows prevailing at the specific time of the day chosen to change from one plan to the next often will be different on each days in the week. Therefore, congestion would occur at the transitions between plans. Several different algorithms to improve the network performance at the transition were developed. Some of these plan change algorithms involved an abrupt change and others introduced a series of short duration plans during the transition. These were referred respectively as FAST and SLOW plan change algorithms and there were several studies of the performance of different plan change algorithns during the 1970s and into the 1980s. These were carried out by Kay and Castle (1971), Bretherton (1979), Worrall et al (1973), Lieberman and Wicks (1974), Kittleson (1976), Ross (1977b), Basu (1980) and others. The research of Bell and Gault (1982) and Bell et al (1983) showed that:

a) The performance of a plan change algorithm did not appear to depend on the frequency of updating.
b) Irrespective of whether a plan change is from off-peak to peak or peak to off-peak, if the change is introduced at other than off-peak flow levels there was always a statistically significant increase in both vehicle stops and traffic delay. Typically 9% extra delay was found to occur if plans were not changed at off-peak flow levels.

Considering the infrequency of updating plans, the quality of data used to derive them, the large cyclic and daily flow variations likely at the plan change time, budget constraints, the reliability of the existing hardware and the computer power to process the algorithms to implement more sohpisticated algorithms, the research endorsed that the MODIFIED ABRUPT method (most commonly used in practice in cities in the UK and throughout the world at the time of the research) was the most effective.

Exactly how many plans should be implemented depends on the significance of the flow changes from hour to hour that are observed in a particular signal controlled region in a town or city. If the resources are available the TRANSYT model can be used to assess the benefits of operating the different signal plans. The research by Bell et al (1983) and Bell (19845) demonstrated that the TRANSYT model is tolerant to random flow variation of about 10% and ignoring special event plans, typically three or four plans were found to be adequate to successfully control traffic in most cities. The traffic engineer must weigh the benefits of operating a more appropriate plan against the extra delay caused by frequent switching between several different plans, and of course, the cost of their maintenance.
In fact, it is better to change infrequently to and from 3 or 4 good fixed-time plans which each operate for two or three hours, rather than change frequently to poorer quality plans which operate for periods of 15-30 minutes MacGowen (1980) and MacGowen and Fullerton (1980) and Bell (1983). Also it is believed that, rather than increase the number of plans, more benefit can be achieved by varying the time-table for switching plans to more appropriately to respond to shifts in the onset and decline of peak hour periods from day to day. As computers became more poweful this became the norm as is the case today.

Ageing of traffic signal plans
The benefits offered by the initial optimised signal plan depreciate in time, as traffic conditions change. The ageing process is related to the stability of flows across the network and the extent of modifications in the capacity of the network, new road building, land use changes and traffic management schemes. In the long term, ageing is often associated with a systematic uniform increase in the traffic over the whole network. This causes increased delay to traffic as the signal plan deteriorates more each year. In fact, the ageing process applies equally to the situations where flows decrease systematically or the overall network flow remains unchanged but the traffic is simply redistributed to alternative routes.

Another important phenomenon related to the ageing process occurs when a co-ordinated plan is first implemented. Because congestion is reduced, the vehicles experience less delay. Often in a very short time vehicles re-route to take advantage of the less congested routes. But by their own act of re-routeing they alter the distribution of flows within the network, and outdate the plan. Some may argue that the rate of ageing of traffic signal plans is large just after a co-ordinated plan is implemented. This principal has been discussed by Allsop (1974) and Allsop and Charlesworth (1977).

Updating traffic signal plans in practice
If minor changes to the traffic signal plans refered to as “tweeking”, are necessary, then a full network update cannot be justified and often TRANSYT is not used. In general, on-street observation of the changes in traffic patterns are made and manual adjustments follow. If these manual adjustments are significant the resulting plan is a second best to a full re-optimisation of the TRANSYT plan budgets are often limited and time elapses of up to ten years were found between full network updates. In essence fixed time plans perform well provided variations in the magnitude of flows remain less than about 10-15%.

By the mid 70's most large cities in the UK and throughout the world implemented area control referred to as Urban Traffic Control, UTC. This was achieved in two ways, either by centralised or distributed control. The cost of the two forms of control were about the same. The centralised form of control employs a large processor with a built-in allowance for expansion. The hierarchical control operates on a building block system. For both systems it was necessary to have two computers, one to back-up the other in the event of failure. In general the computer system requires trained staff to enable continuous surveillance of the network. Some UTC systems used close circuit Television, CCTV, most allowed operator intervention and all provided comprehensive checking facilities to ensure that the signals operated correctly.

The technological progress with traffic signalling equipment, the advent of microelectronics, Evans (1978), Davies (1984), and advanced computers with improved reliability have reduced both the capital and running costs of UTC systems. Network control in the form of Compact Urban Traffic Control (CUTC) has been a feasible proposition even for the smaller towns, since 1980. Guidelines of how to plan; prepare for and use CUTC have been proposed by Phillips (1982) and the system is described by Stannett and Sullivan (1981). It uses a dedicated computer with significant power and reliability to operate without a back-up computer and staff surveillance. The early CUTC systems were installed in Devon and Humberside, Redfern and Shapely (1981), in Hull and Torbay, Bernard and Hillen (1981), and elsewhere in Brighton and Hove, Chessell (1981). CUTC has much potential for influencing a basic system change in UTC from a central to a distributive processing strategy.

By the beginning of the 1980's there were about 250 UTC systems in operation around the world, Hunt et al (1981, 1982). Such UTC systems proved to be justly popular as urban traffic management tools because they benefit traffic without damaging the character of the town, and also tend to achieve reductions in accidents, vehicle noise and exhaust pollution, OECD (1977). UTC systems continued to be exploited to establish such things as priority routeing for buses and fire appliances, route guidance for vehicles towards free space car parking and away from congested areas. Hawkins (1979), Andrews and Hillen (I 980), Redfern and Shapley (1981), Stannett and Sullivan (1981), Bernard and Hillen (1981) and Phillips (1982).

However increase in car ownership caused networks to operate with less spare capacity and even short periods of high or low demand created recurrent congestion, fluctuations in flows increased during off peaks and consistency of time when plans changed changed. Methods to overcome these limitations led to research to develop concepts of demand responsive UTC. Early systems required frequent switching to different traffic signal plans in response to actual traffic flow changes detected in real time.

There are three levels of demand responsive systems. The first generation systems, often referred to as 'semi-responsive', use continuous monitoring of flows at key junctions to automatically trigger an appropriate fixed-time plan selected from a library of plans stored in the computer memory. There is little evidence to suggest that 'semi-responsive' systems consistently produced significant benefits over the simpler fixed-time systems, Ferguson and Jenkins (1973), Luk et al (1982).
Second generation control systems produced optimised signal plans in real time. These were derived using current traffic counts to update historical data at regular intervals. These systems required more powerful computers and tended to have the ability to implement the more complex plan-change algorithms.

Third generation control systems, researched in the 1970's that were fully responsive systems calculated the new signal settings continuously, KLD Associates Inc. (1974), Lieberman et al (1974). However, research by Holroyd and Robertson (1973), MacGowen and Fullerton (1980), Humphrey and Wong (1976), and Rach (1976), demonstrated that fully responsive UTC systems were difficult to develop. The main reasons why these early demand responsive systems showed insufficient merit was because the predicted flows, over small durations of typically 5 to 15 minutes, based on either or both historical and real-time data, were found to be poor, Kreer (1975, 1976), Eldor (1977), McShane et al (1976), Knapp (I 973), Nicholson and Swann (1974), Gazis and Szeto (1974), and others. The prediction was found to be less reliable the shorter the duration. However, the shorter the duration the higher response to changes in traffic demand and greater the benefits, Guberinic and Senbom (1978). The lowest practical limit for a co-ordinated system was found to be 5 minutes, Eldor (1976).

However frequent plan changing, even when supported by more sophisticated plan change algorithms, causes disruption; particularly at high demand, Bretherton (1979), Bell and Gault (1982), and Bell et al (1983). The early systems generally had slow response to traffic demand. Furthermore, the effects of making incorrect decisions as to when best to change, and to which plan, were fairly significant. It was for these reasons that the fixed-time systems were adopted as a national standard in the UK throughout the 1970's.

However, Holroyd and Robertson (1973) suggested a methodology which attempted to avoid these problems. This demand responsive control philosophy uses an on-line computer which continuously monitors flows entering all links in the network, predicts short term (every cycle) traffic arrival patterns at the stop-line, and makes small adjustments (typically 3-4 seconds) to the traffic signals in an optimal way. This control philosophy formed the basis of the SCOOT (Split Cycle Qffset Qptimisation Iechnique) system and its development was a co-operative venture between UK private industry and Government departments, This novel concept of demand responsive control system minimises transients and has a fast response because it is based on a short term prediction (typically every cycle). It requires no starting plans and performs its own detector monitoring and fault recording. The SCOOT strategy was successfully demonstrated in Glasgow and Coventry under a wide-range of conditions, Hunt et al (I 981, 1982), Robertson and Hunt (1982), Bretherton and Rai (I 982), and Clowes (1982), and the first commercial SCOOT system was installed in Maidstone in 1983, Boumer (1984). SCOOT is primarily a signal control strategy, and as such it does not replace conventional UTC systems, but rather works in co-operation with them. The 'kernel' SCOOT software, as produced by the joint development team starts with the analysis of raw detector data and ends with the recommendation of signal timings. All the standard UTC functions, such as transmission drivers and fault monitoring, are still required to make up a complete system. SCOOT can be thought of as a "black box" within or attached to, a conventional UTC system, Walmsley (1982). But fundamentally SCOOT is an on-line TRANSYT which substitutes the modelled cyclic flow profile at the top of the link with that measured in realtime cycle by cycle using traffic detectors.

Research by Bell (1984) showed in a study of TRANSYT networks that grid networks aged more than radial networks and on average a benefit of 3% per year was found over not updating signal. These metrics enabled LA to estimate the financial savings of implementing the SCOOT system which obviated the need to update signal plans. The research showed that typically the investment in SCOOT benefits was fully recovered 9 to 15 months in most networks.

Other demand responsive control systems have been developed and employ completely different control philosophy such as SCATS (Sydney Co-ordinated Adaptive Iraffic System), developed in Australia, Moore et al (1976), Luk (1981). SCATS derives traffic flow and occupancy from detectors placed in each lane immediately in front of the stop-line. The system assess degree of saturation to adjust splits and uses the information to assess the desirability of linking major intersections. If so, one of four predetermined linking plans is selected along with offsets. Moore et al (1976), claimed large benefits of the SCAT system over the conventional fixed-time systems and Luk et al (1882) suggests the SCAT system works effectively along dominant routes.

Expert Systems of Control

As the technology advanced and computers became more powerful further sophistication was introduced to manage short term, recurrent congestion events. Research funded by the EU in Leicester in collaboration with INRETS in France developed the CLAIRE expert system of control, Bell et al (1991). This was one of the first applications of artificial intelligence to traffic control which learned from the detector data the nature of the build-up and evolution of recurrent congestion events and selected an appropriate signal plan from a library of previously designed remedial strategies. Research of Withill (1992) under the supervision of Bell studied the re-routing of traffic in response to variable message signs indicating car parks were full. This showed that drivers did not chose the nearest empty car park but showed a tendency to divert to specific car parks at different times and days of the week. This led to sets of action plans to override the SCOOT decision making in response to specific triggers. With the introduction of new technologies traffic operators now have a set of tools that they can use to tailor UTMC to meet their specific traffic control policies. However, despite increased sophistication in technology, increased ownership of cars, their use and for longer journeys, has meant that traffic congestion remained a problem with the unintended consequence of poor air quality which initially was brought to the attention of LA back in 1995 but remains a concern today.

Traffic related Pollutant Emissions in Urban Areas
Research commenced in 1987 using the TRANSYT model to estimate the effect on emissions of fixed time signal co-ordination and recommendations were made to increase discharge of queues at specific stop-lines by splaying stop-lines to alleviate build-up of queues. But there were limitations due to the lack of good quality emissions data and without roadside monitoring it was not possible to explore the effect traffic flows were having on kerbside pollution or even to validate pollution models. Early studies that investigated the relationships between traffic flows, speed and roadside concentrations Reynolds (1991) used portable carbon monoxide systems. However, surveys were limited to dry weathers due to the sensitivity of the equipment to humidity and restricted to short duration (up to about two hours during morning and evening and off peaks periods) surveys because the equipment needed to be manned for security. Simultaneously with the concentration monitoring, traffic was counted, classified and speeds were measured. These studies revealed very weak relationships between pollutant concentration and traffic variables due to the huge variation in traffic flow, meteorological conditions (wind speed and direction) and the complexity of the relationships between traffic emission and concentration given the chemical and physical processes that govern the dispersal of pollution in the atmosphere. This work confirmed the need for continuous kerbside pollution monitoring.

It was 1997 before the first pollution monitors were developed by Siemens in collaboration with Nottingham University which enabled correlations between the traffic data available as a bye product of the from SCOOT control and the roadside concentrations to be explored. Research by Jalihal (1999), demonstrated that whilst congestion was clearly influencing the pollutant levels measured at the roadside there was no correlation with the SCOOT delay, stops or the congestion measures CONG or RAW. There was a stronger relationship found with the degree of saturation but for all traffic flow situations. Research carried out on the M42 which measured the real-world emissions simultaneously with speed knowing its position with respect to the MIDAS detectors it was possible to assign the aggregate emissions to the speed flow of the general traffic. This clearly demonstrated that the flow regime described by both the speed and the flow was a better indicator of pollution emission rather than any one specific variable. The results shown in Figure 2 showed that NOx emissions were measured to be 3 times compared to the other three flow regimes, Bell et al (2006). This led to further research which evaluated a combination of SCOOT modelled parameters to investigate correlations of composite measures of occupancy and flow to assess the effect of congestion.

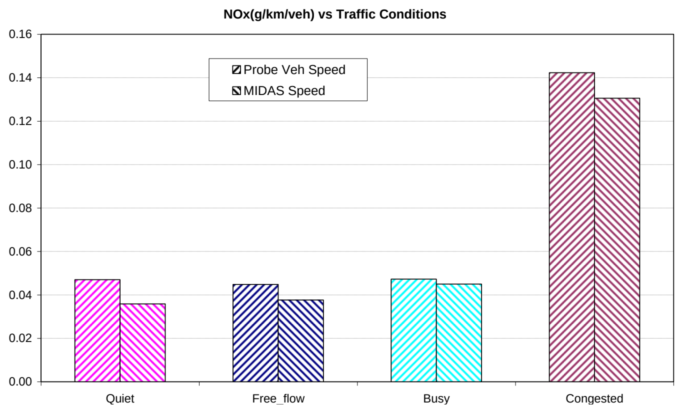

Figure 2 Tailpipe emissions depending on the flow regime measured simultaneously by MIDAS detectors on the M42, Bell et al (2006)

Enhanced Emissions model.
As well as flow regime, pollution emissions are a function of the vehicle type, age (Euro classification), fuel type, engine size. The UK Government gave Local Authorities the responsibility of assessing and delivering the air quality objectives. The emissions factors are available as a Toolkit from the defra, Department of Environment Food and Rural Affairs website, DEFRA(2019). Usually the recommended National Fleet is used to provide typical traffic characteristics of the vehicle fleet for different types of road is used. However, ideally, if the number plates of vehicles are available for traffic it is possible, at a cost, to use the dvla, Driver Vehicle Licencing Authority, to purchase vehicle licencing data to define the actual fleet characteristics for a more accurate estimate of emissions. The SCOOT traffic flow and occupancy, available cycle by cycle, is used to assign the traffic flow with a

regime either free-flow, smooth-flow, unstable or congested. Using the data in the Emissions Factor Tool Kit the total emission for the traffic travelling in the assigned flow regime is estimated for each five minutes. These algorithms have been coded in the product AQATANE by Amey Consulting which allows the data to be presented on a 2-D map with links between junctions changing colour red, amber, and blue, green depending on the magnitude of the pollutant emission. The latter can be either nitrogen dioxide, NO_2, carbon monoxide, CO, carbon dioxide, CO_2 or particulate matter, PM10. Knowledge where excessive levels of pollution are being emitted is necessary to be enable traffic intervention measures to be taken.

Pollution Concentrations

However, whilst these estimates of pollution emissions advise engineers where the pollution is emitted, it does not necessarily inform where the pollution problems are occurring in the network. This is because the meteorological conditions, influenced by the built environment, along with the chemical interactions between pollutants actually govern which pollutant and where pollution builds-up. Therefore, there is a need to use the emissions in a dispersion model, to estimate the pollutant level at specific locations in a cross section of a street. The dispersion model used in AQATANE is the canyon model OSPM, Operational Street Pollution Model KAKOSIMOS (2010) which requires both the meteorological conditions (magnitude and direction of the wind) along with the heights of the buildings and the façade to façade spacing. Typical levels of pollution predicted in a cross section of a Canyon depending on the direction of the wind is shown in Figure 3.

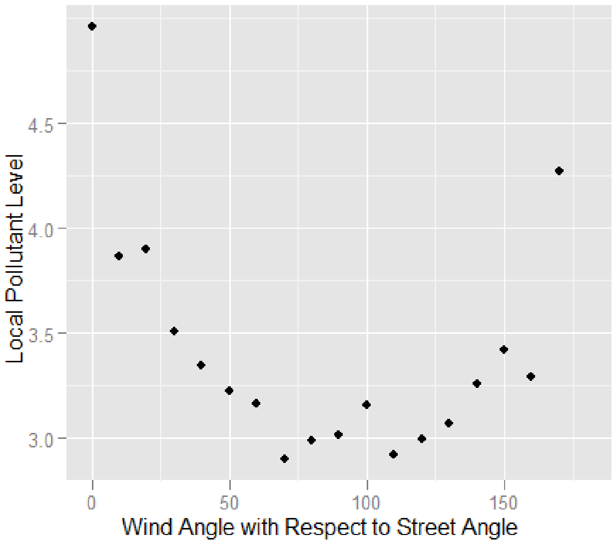

Figure 3. The effect on pollutant concentration depending on wind direction estimated using the OSPM model. Note 90° represents the wind when it is blowing in the direction aligned with the street. Hill (2015)

Figure 3 clearly shows that local pollutant levels are highest when the wind is oriented perpendicular to the alignment of the road and pollutant concentrations build up on the lee sides of the road (0° and 180 °in the figure). Pollutant levels reach a minimum as the wind shifts to a direction parallel with (blowing along) the road (90°in the figure). This is consistent with increased dispersion from the induced vortices ventilating the street. The heights and width of the street as well as the strength of the wind also affect the rate of dispersion. Pollution builds up when wind speeds are low and in steep continuous canyons.

At junctions, depending on both the levels of traffic, prevelence of congestion and the general openness of the built environment governs whether a hotspot occurs. Of course open spaces such as fields, parks are places where there is natural ventilation of traffic related air pollution, locations that experience lower levels of pollution concentrations even though emisions may be high. Also, emissions are higher for vehicles travelling uphill, especially if queues build up when stopped at traffic lights, therefore it is advisable to create green waves to avoid stopping vehciles travelling uphill.

The effect of the wind on pollution across a network is illustrated in Figure 4, Hill (2015). The use of data available as a by-product of UTMC and Intelligent Transport Systems per se enables concentration maps across a city area to be created in real-time based on emissions data calculated every five minutes. The emissions are summed to estimate pollution concentrations every hour using OSPM. By archiving data over several years it is possible to use the models off-line to hypothetically explore the effect on hotspots of implementing policies to introduce clean vehicles (eg. investment in low emission buses, penetration of electric vehicles).

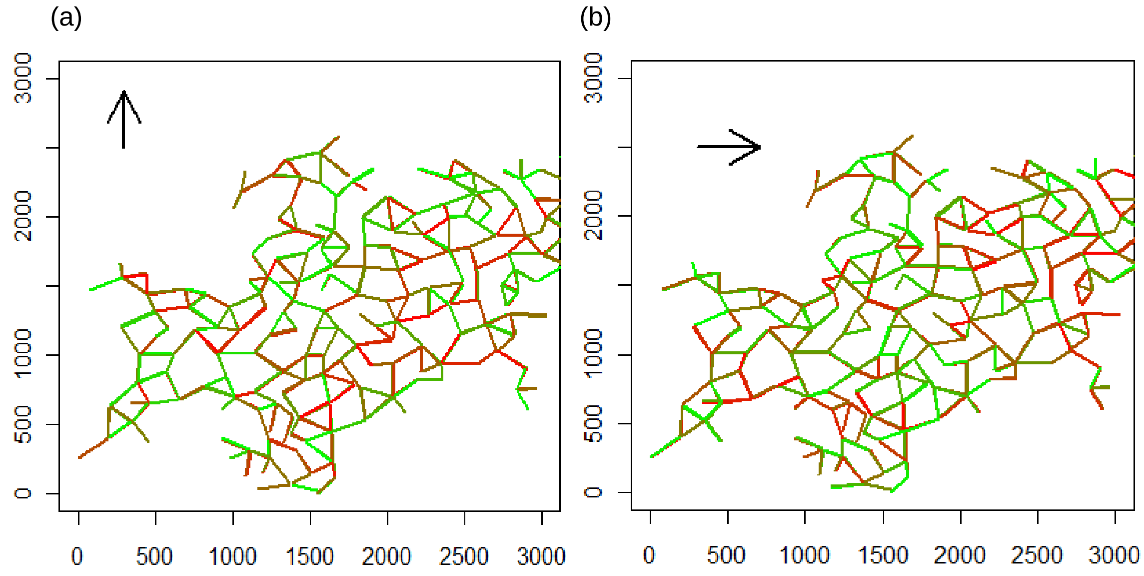

Figure 4. The effect on pollution concentrations calculated using the OSPM model on links in a network depending on (a) northerly or (b) westerly wind.Hill (2015).

Managing Air Quality using UTMC

The OSPM, is the model commonly employed in grid dispersion models including ADMS Urban CERC (2020) and Airviro, Apertum (2020). These use average flow, average speed pollution emissions factors which provide reasonable pollution estimates usually on an hour by hour basis and over grid squares of typically 250mx250m. Furthermore, these air quality models tend to use modelled traffic rather than measured data often available for peak periods only. This means assumptions are made about the hourly daily traffic flow profiles. Whilst the emissions factors to some extent accommodate congestion effects, these are averaged over distance. Therefore, as such these models are not useful for identifying which link(s) in a network are causing elevated pollution specifically due to congested related emissions.

The potential to use actual traffic data available as by product of UTMC, Urban Traffic Management and Control to estimate the hourly canyon pollutant concentration level based on 5 minute emissions estimates using actual traffic flow regimes, offered real opportunity to better understand where those links in a network that are prone to the build-up of pollution are located. Coupled with the ability to predict emissions on a five minute by five minute basis to understand the traffic source characteristics (unstable or congested flow) responsible for creating the pollution, remedial measures can be designed to deliver the environmental objectives. Several studies have explored intervention methods to alleviate recurrent congestion related pollution. Tate (2000) demonstrated how queues can be relocated from closed to open space by simply changing the offset and cycle time between consecutive junctions. Important lessons emerged from this study. The first was the importance of modelling the changes made to the splits, offsets and/or cycle time and using traffic assignment (in this study SATURN) to predict their effect on route choice. TRANSYT subsequently was used to optimise signal timings on the alternative routes. The reassigned traffic flows and speeds were then fed into an air quality model which confirmed that the rerouted traffic did not result in the displacement of the pollution problem. This provided confidence that strategy was be beneficial. The second was the fact that the public were rather unsympathetic towards the scheme with many complaints concerning the build-up of queues in a part of the network where traffic normally travelled freely and yet journey times remained unchanged and traffic at the downstream hotspot junction ran freely. This demonstration attracted some very bad press which was rather unfortunate given the trial was a complete success. An important message emerging from this demonstration was the flexibility of traffic signal control which allows engineers to easily change signal control parameters by a few seconds, to subtly achieve the desired change in signal plan by gradually relocating the queue a vehicle at a time.

The TRL carried out a trial of cascading of queues along a radial into the city of Leicester to alleviate the build-up of pollution in the vicinity of the Central Railway Station by spreading the emissions systematically onto upstream links. This study showed that with a combination of adjustments to offsets and splits delivered significant reductions in emissions on the polluting links. However, this study did not carry out the more strategic modelling to assess any displacement of queues on re-routeing to evaluate any consequential pollution displacement. Interestingly, this research did highlight a different political issue. The scheme caused queue build-up in the neighbouring local district of Groby at the periphery of the city. This confirms the need for a collaborative approach across regions when resolving environmental problems. Another study of pollution hotspots in Leicester City demonstrated that the only way to have significant impact on city centre pollution was to facilitate a mode shift to public transport. Consequently six park and ride sites were planned. Iterative modelling between SATURN and TRANSYT followed by air quality modelling using Airviro showed that whilst the total pollution emission across the Leicester conurbation only reduced by $14\mu g^{-3}$ the air quality hotspots were remedied.

Re-engineering networks.
Traditionally the two main principles controlling traffic in networks are (a) to respond to the times of travel and routes chosen by vehicles and (b) to minimise delay and stops, manage queues and alleviate congestion. However, given that signal control is designed to manage traffic which choses routes to meet the desired destination it is well known that signal control can influence drivers' route choices Allsop (1974), Allsop and Charlesworth (1977). Therefore, instead it is proposed that the signal timings for junctions in a network are "engineered" to deliver the environmental objectives, both in terms of carbon emissions and air quality. In this respect it is necessary to change the fundamental design principles and use UTMC and intelligent transport systems.

Control and Management of Air Quality in Networks
The basic concept of an *environmental capacity* to optimise control and manage traffic in a network was presented in Bell (2011). For urban areas there are two approaches. The first is to control traffic to manage the more pressing issue of poor air quality and secondly to optimise traffic to reduce total eCO_2 emissions across a network.

At today's traffic flows AQMA, Air Quality Management Areas, are declared where a particular pollutant exceeds certain limit values, in most areas in UK this is due to elevated NO_2 rather PM10. Larger areas are declared as AQMA because it is necessary to manage traffic over an area despite the fact that the pollution 'hotspot' is constrained to particular junctions or links. Tactical signal control adjusts splits reduce the volume of traffic entering a link where pollution builds up (due to orientation of road with respect to the prevailing wind and ratio of height of buildings to the façade-façade distance) and/or by changing offsets between consecutive junctions to hold traffic in streets with natural ventilation (open spaces, for example parks and fields, and streets parallel to the prevailing wind). Even short links with low flow but persistent queueing can become polluted depending on the built environment. Such constraints on signal timings manifests an area signal plan sub-optimal creating more delay to side road traffic, these remedial actions aim to *spread the emissions around* . There is a need to be mindful of the build-up of pollution on side roads due to displacement of traffic, in which cases steps need to be taken to incentivise the use of park and ride and sustainable modes to reduce demand. Given that pre-COVID areas of urban networks were consistently failing to meet environmental objectives, CAZ, Clean Air Zones were being considered seriously in cities across the UK, to limit access to only low emitting vehicles. However research by Cairns (2012) in Leicester which modelled the impact of introducing electric cars into our fleets showed that even with 100% penetration PM10 levels would reduce by only 20%. Given there is no safe limit of particles, this suggests that there is need to reduce vehicle kilometres travelled and a radical behaviour change with a shift to sustainable travel particularly in vulnerable areas of the city.

Optimising networks to reduce carbon emissions
Notwithstanding tactical control, Local Authorities should give serious consideration to adopting a policy which optimises networks to minimise total air pollution which is synonymous with optimising fuel consumption and carbon dioxide emissions. However, this would achieve about a 3% reduction in

emission across the network. However, at today's traffic levels this is insufficient to prevent air quality exceedances at specific junctions and roads. By implementing tactical the area traffic plan is shifted away from the optimal solution and increases carbon as traffic spends time idling for longer at stop-lines and rat-runs making journeys longer. Developing win-win strategies for carbon and air quality with tactical control is difficult to achieve. Whilst many people believe that new vehicle technology will *save the day* research by Cairns (2012) modelling traffic in Leicester at 2005 flow levels showed that for private cars 96% penetration of electric vehicles would needed to deliver the mandatory eCO_2 limit, but of course levels of traffic have increased since then. Cairns concluded that realistically, given that a similar of penetration electric buses and heavy goods vehicles would be unlikely, the only way to deliver on targets was to reduce the VKT, vehicle kilometres travelled.

Delivering the mandatory UK Government target of 67% reduction of eCO_2 by 2050 over 2010 levels as well as meeting air quality targets poses interesting questions. "Just how much traffic, with future low emission engine technologies, can be allowed to use the network?" and "Can the impact of lockdown on traffic levels, the environment and travel choices inform network control and management to assist in re-imaging our future networks?"

Post-COVID social distancing has reduced the capacity of buses to 15%-20% and people are using their cars more to avoid contact with others, the future is uncertain. Whilst many more people have purchased cycles and levels of cycling have increased dramatically, as we approach the winter months it is anticipated that people will move towards alternative, likely private transport. Of course economic recovery requires movement of goods, delivery of services and people travelling to shop, to work, for personal business and leisure. The question arises: "Can network management and control be re-imagined to support economic growth by putting environmental objectives first?"

Re-imagining networks.

Rather than accept the inevitable consequences of lockdown, decline in the use of public transport, reduction in cycle use in inclement weather and increase in private car use, it is suggested that the situation we find ourselves in is turned into an opportunity. By working collaboratively with the bus operators, Schools, Local Authorities and Businesses, UTMC and ITS can play an important role reimagine our future networks. A future that reduces the need to travel, influences mode shift to sustainable modes and manages traffic in networks to deliver environmental objectives. This requires pedestrian and cycle focussed policies in controlling networks with emphasis on the provision of door to door seamless travel by a combination of sustainable modes. This will require a fully integrated approach and cannot be delivered over night. However, co-creating an evidence based re-imagined future urban area, incremental steps can be designed to re-engineer our networks and produce a road map. Engagement with the public is essential because by sharing the ambition and giving ownership of solutions maximises the success of uptake. This can only be achieved by understanding the public's barriers to change whilst simultaneously presenting evidence of the need to act and how sustainable travel choices can make a difference. Given every town, city, urban area is unique how a re-imagined future will be designed and delivered will be different, some ideas and approaches are now presented.

Reducing demand to travel

Given the success in working from home, WFH, companies are considering accepting this as the norm in the future for staff if not all the time but on few days each week. Whilst to be encouraged a study of the CO_2 emissions from the energy use (gas, electricity and for travel) over a period of one year in 575 households in Leicester, Allison et al (2016), suggested that the 50% of gross emitters of CO_2 were annually responsible for 96% of transport emissions and 60% of gas and electricity. The same research suggested that on average if people work at home and use gas, electricity to heat (or cool) the home they on average emit 75% more CO_2 than saved on average by not using the car to travel into the place of work. This has implications if people continue to choose to work from home post-COVID during the winter months.

A positive aspect of WFH is reduced vehicle demand for parking spaces in city networks and reduced congestion and pollutant emissions however it does have implications for well-being and mental health of the working population. It is suggested that efforts to create facilities for hot-desking with printing and scanning services, secure wifi and video conferencing facilities within walking and cycling distances from homes. This would mean that several people can interact on a regular basis saving energy (and carbon emissions) and overcoming the effects of isolation. Such facilities could develop dynamically at coffee shops in local villages, at bicycle shops or in the future integrated within new housing schemes or public transport hubs acting as catalysts for existing and new businesses.

Evidence is emerging that in-town and city business is falling causing large department stores and take-away food shops to close. This is due to the growth in on-line shopping coupled with reduced footfall during the day due to employees continuing to WFH due to social distancing requirements in offices and places of work.

As city centre and out of town retail businesses begin to close down and potentially also future office blocks, real estate will become available. Therefore to avoid areas becoming blighted grants should be awarded to repurpose buildings for housing targeting the younger population and essential workers as residents. Businesses should become more proactive in encouraging staff to use sustainable travel options, perhaps offering incentives (for example interest free loans for purchasing homes instead of a company car) to live locally with an undertaking to walk or cycle daily to work. Such housing may also be repurposed for the elderly population to be close to amenities. Shared mobility services to encourage city dwellers not own cars but to use electric vehicles when needed can be integrated with such city centre developments.

Businesses should be proactive and use postcode data of their staff to arrange out of phase WFH practices to more effectively use workplace carparks from day to day, and provision of secure convenient cycle storage and showering facilities which will be needed if well-known barriers to cycling are overcome.

Creating mode shift to public transport

The first step to creating a shift to sustainable modes is, through targeted campaigns, to re-instate the publics' confidence in using public transport. Incentives can be put into place to incentivise public transport use. These include purchase of travel cards (through company schemes for example) which allow seats to be booked for regular journeys but on fewer days in the week, carriers for transporting cycles, secure parking for bicycles at public transport hubs. An integrated approach to facilitate door to door services with seamless transfer between modes including with private vehicles requires investment in shared mobility facilities to provide first mile last mile services.

As companies, restaurants, shops and schools respond to meeting social distancing inside their premises, they should also give thought transport needs of their staff customers and clients. In the interest of maintaining public transport services financially viable into the future there is scope to begin to explore a change of policy for timetabling of bus services suggesting that operators consider tailoring bus services to meet the public's need.

Acknowledging that public transport is at the heart of a sustainable future, operators should consider working with:

- Education Authorities teachers and parents to tailor services to meet the school run, with an undertaking by parents to accept public transport as the main access mode across all ages.
- Companies and businesses to understand how bus services can be tailored to meet changing business practices (WFH, social distancing etc) influencing work patterns with shifts starting earlier and later to accommodate the use of buses for the school run and spread the demand for seats on public vehicles across the day.
- Retail outlets and city business community groups to again tailor opening times to compliment the demands for school and commuter travel.
- Consider dual purpose of use of buses with compartments for delivery of packages and shopping to out of town hubs, with racks on the rear to facilitate cycle carriage perhaps engaging with shared cycle schemes to transport cycles to places where they are needed.

Implications for traffic signal control and management

The ITS community can boast decades of research and a legacy of skills and expertise upon which they can build to support re-imagined futures. What they also have is the wealth of data available as a by-product of the application of UTMC systems and ITS technologies. Presented here are some suggestions moving forward.

Given there will be traffic, air pollution and meteorological conditions data available historically an analysis of such data along with the data captured during and since lockdown will help to identify how traffic influences the levels of pollution with the ability to establish the threshold level of traffic flow and congestion at which the air quality objectives will be delivered.

Canyon modelling assuming a dirty and clean year will help to establish a range for the threshold value for each link and hypothetical intervention measures (low emission buses, penetration of electric vehicles etc) can be evaluated. This understanding combined with an evaluation of carbon and pollution emissions will help to inform the size of the challenge facing the traffic manager in delivering a re-imagined future and what effort is needed to re-engineer travel appropriately.

Set up routine data capture from existing UTMC and ITS on an integrated data platform and use the data on a five minute sampling time to estimate traffic emissions to understand sources of traffic related air pollution and use a canyon model to predict where and when pollution hotspots occur in the network. There are potentially many reasons for elevated emissions including, ageing public transport fleets, excessive queues, the built environment, pedestrians and bus stops interrupting traffic flows, etc but this understanding will inform the design of intervention measures.

Use an emissions sensitive Performance Measure to penalise traffic on sensitive routes according to the offending pollutant. Networks optimised to reduce NO_2 will have be different signal timings if PM10 or CO_2 is minimised. Traffic engineers can explore tactical control combined with reductions in cycle time over areas to slowly reduce the capacity of networks for private cars whilst reducing delay to travel by sustainable modes as initiatives to promote mode shift to public transport and cycling.

Over time as the focus of the Performance Measure moves towards the delivery of environmental benefits more capacity is shifted to public transport, cyclists and the pedestrian. At this point traffic engineers need to address whether there is a need to revisit the basics of signal junction design and optimise timings to provide green waves for buses, cycles as well as pedestrians. How do we effectively manage the interaction of these three modes at junctions as the bus, cycle and pedestrian flows increase? Are our geometric design principles adequate and what changes are needed to the design calculations?

Knowing passenger occupancies will become more and more important; the use of mobile phones for checking services and bus arrivals means that public travel patterns can be tracked also. However, issues of data protection and sensitivity in competitive markets need to be addressed to successfully manage seamless travel across the modes.

More emphasis will be placed on delivering safe areas for people to move and enforcement of bus and cycle lanes will be needed. Access and egress to shared mobility facilities and managing secure parking for ever increasing bicycles will be needed. The physical layouts of roads and networks to accommodate changes use of modes (wider pavements for passengers' queueing at bus stops), cycle and pedestrian congestion.

Final Comment

This paper in setting the scene for the need to re-engineer and re-imagine future networks and to offer some ideas for the future is by no means complete. Instead, the purpose was to present food for thought and to sow seeds as basis for debate. Sustainable transport delivers win-win for carbon and air quality but active travel also has positive benefits for health, tackling obesity, heart disease to name a few. Reducing the amount of traffic in networks means less local pollution emissions resulting in cleaner healthier urban areas. This win-win-win sets out the basic principles for future policy and traffic signal control and management which aim to put people first.

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Session Two

Paper Traffic Signals Under SCOOT Control: Effective Design Principles.

By Jackie Davies - Bristol City Council

Traffic Signals Under SCOOT Control: Effective Design Principles

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Summary

Traditionally, SCOOT has been considered to be suited to congested urban networks and MOVA has been considered to be suited to stand alone junctions. With the introduction of linked MOVA, the lines have blurred significantly between SCOOT and MOVA. This has led to a long running debate as to which is 'best'.

In reality, the 'best' form of control at a junction depends on a wide range of factors. The purpose of this paper is to detail junction design issues that can assist or be detrimental when designing a site for SCOOT control.

How SCOOT Works: The Basics

SCOOT is a real time traffic responsive computer model that receives live traffic signal green times and vehicle presence measurements from detectors on-street on a second by second basis from the traffic signal control system.

The SCOOT model automatically adjusts the traffic signal timings to provide more green on the busier approaches when required. The model also takes into account the relative effect that the green time on each approach has on the surrounding traffic signal network and adjusts the green time to minimise delay across the network, whilst also generating offsets between the sets of signals to maximise junction capacity, by minimising exit blocking.

In order for SCOOT to model the traffic within the network correctly, and therefore give the correct amount of green, there are a number of model parameters that must be entered. The most critical parameters for modelling the SCOOT link are:

- Journey Time (JNYT/ JTIM): The average free-flow journey time for a vehicle travelling between the detector and stop-line.
- Maximum Queue Clear Time (QCMQ/ MAXQ): The time taken for a queue that reaches all the way back to the SCOOT detector to cross the stop-line.
- Saturation Occupancy (STOC/ SATO): This is the discharge rate across the stop-line for traffic during green.

SCOOT applies the above parameters to the traffic signal and vehicle presence data. Using these values, along with the signal green times and vehicle presence data, the model determines the current queue length, the time required to clear the queue and the point at which the back of the queue begins to move off. SCOOT uses this to determine the most appropriate stage length, cycle time and offset between traffic signals.

SCOOT makes a number of assumptions that must be correctly managed to keep it running well. These are:

- SCOOT Link Saturation: The SCOOT model tried to keep all SCOOT links at a junction operating at the same level of saturation at all times. This may be inappropriate where a junction approach is a rat run, or is severely exit blocked at busy times. Parameters can be put in place to manage this, but there must be space to queue the traffic which builds up during peak times on less important approaches.
- SCOOT Cycle Time: The SCOOT model assumes that a higher cycle time will improve the junctions' efficiency. This may be an incorrect assumption and the maximum cycle time may need limiting. This could be due to the presence of flare lanes, or exit blocking. All SCOOT nodes in the region should be able to run this same cycle time.
- SCOOT Offsets: The SCOOT model will try to provide an offset for all links at the same time. In trying to provide a good offset on all approaches, there is risk that the SCOOT model can end up providing a poor offset on the most critical approach. This

means that junctions requiring multiple offsets to work well can be problematic. This needs consideration at design stage.

SCOOT Junction Design Principles

Junction and Region Cycle Times

The SCOOT system provides offsets via the provision of a common cycle time for all traffic signals within a SCOOT region. It determines the most appropriate point in the cycle time to commence the downstream traffic stage, enabling the upstream stage to progress onto the back of a moving queue.

This need for a common cycle time is the most restrictive factor in terms of the SCOOT model's efficiency. It creates a number of issues to be aware of when designing a junction which will be part of a SCOOT network. It is important to ensure that the Junction being designed can work within the SCOOT region that it is sat within. This decision is usually based on two key questions.

- Cycle Time: What cycle time will the site need to run at during the peak and off-peak periods to manage traffic demand? Does this match with what the rest of the SCOOT region needs? If the site has more or fewer stages, or is significantly busier or quieter than the surrounding sets of traffic signals, it may not be possible to run a common cycle time.
- Proximity: How close is the site to the surrounding junctions and do the queues from this site interact with the surrounding sites, making offsets critical to the operation of the network? Where the queue lengths cause exit blocking for other movements at the upstream junctions, offsets are critical and the cycle time may need limiting to manage queue lengths.

The answers to these questions are central to how well the SCOOT model will be able to generate offsets for the site.

Cycle Time: Where No Common Cycle Time Can Be Found

If no common cycle time can be found, the SCOOT engineer has to either:

- Put the site into the same region and force it to double cycle. This is common at pedestrian crossings as it minimises delay for pedestrians, but still allows the retention of an offset for traffic progression.
- Put the site into a different region and sacrifice the offsets for an optimum cycle time. This will allow the site to run the timings it needs to, but the site may cause or experience exit blocking at busy times, affecting the local network.
- Put the site into the same region and run an inappropriate cycle time, which will make the junction less efficient, but will retain an offset with surrounding junctions. If the cycle time required by the anomalous junction is too high for the rest of the region, it will cause the rest of the region to run long greens when they are not required, which leads to driver frustration when waiting at a stop-line with no traffic coming on the other approaches. If the cycle time required by the site is lower than for the rest of the region, the same effect is caused, but at the anomalous junction only.
- Put the site into a sub-region, so that it can run in isolation from the rest of the region during quiet periods. This is helpful where the issues only occur during quiet times of day, but can only help where a Junction needs a lower cycle time for part of the day.

Each of these choices has a disadvantage, which will impact the efficiency of either the individual site, or the rest of the region. It cannot be fully mitigated by the SCOOT engineer.

Proximity: Where Proximity to Surrounding Junctions Causes Congestion

Where the distance between junction stop-lines is short, it is common for the queues from the downstream junction to reach back to the upstream junction and cause problems for all movements at that site. The SCOOT engineer must ensure that the queue length does not cause exit blocking for other movements at the upstream junction, so they may have to cap the maximum cycle time. This manages queue lengths by preventing the queues from getting long enough to interact with other movements. Where cycle times in the rest of the region make this inappropriate, this is problematic.

It may be possible to model exit blocking issues by installing an exit detector, but this will have only a limited effect at managing the problem.

Ensuring that the junction is designed in such a way that it can run in cooperation with the rest of the local network is vital to maintaining the efficiency of the local network.

Factors Around Junction Staging

The SCOOT model cannot contravene any of the safety critical timing values entered into the controller specification. As SCOOT provides a common cycle time, it has to ensure that all stages that may need to run in a cycle can be accommodated within that cycle. This means the model is limited by the controller's minimum stage lengths and minimum permitted cycle time. The minimum stage length is the sum of the following:

- Controller stage minimum: This is the highest stage minimum of all phases running in the given stage, not counting any phases which run in the preceding or following stage.
- Controller preceding inter-stage: This consists of the highest values that might run, including on-crossing extensions, phase delays, all red extensions, lamp monitoring additional inter-greens and SDE/ SA extensions.

The minimum cycle time is the sum of all of the minimum stage lengths added together plus four seconds.

The minimum stage length for each stage is accommodated by the SCOOT model, as it allocates a period when that stage can run. If the stage is not demanded, this 'spare' time must be allocated to another stage in the plan line, to maintain the common cycle time across the region. This creates a problem at quiet times, as the SCOOT model will optimise the named stage, then call the next (demand dependent) stage, which may not be demanded. If it is not demanded, the SCOOT model will dwell on the named stage for the duration of that stage. It will only then move to the next stage. This creates a situation where the traffic signals can be sitting on a stage, with no traffic coming, at quieter times. This can make SCOOT inefficient during quiet periods.

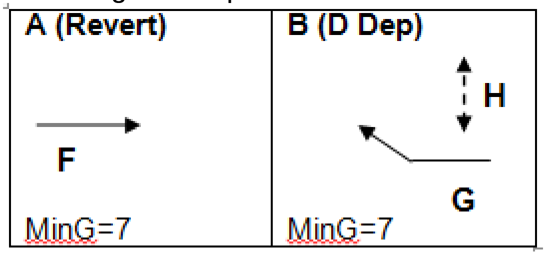
When creating SCOOT plan lines, accommodating these demand dependent stages can be tricky. This creates a number of issues to be aware of when designing a junction to operate under SCOOT control. These are discussed below.

Number of Stages & Staging Order

When creating a SCOOT translation plan line, it is essential that the Force bit being sent matches to the Reply bit being received, once the inter-stage has timed off. For this reason, when there are demand dependent stages on the site, it is essential to specify the demand dependent stage you wish to call, and provide an alternative for if that stage is not demanded.

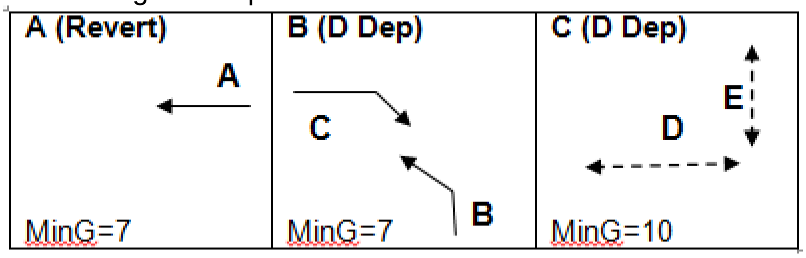
Junctions with two or three stages are therefore easy to accommodate in SCOOT. It is very simple to remain on the named stage, rather than change to the demand dependant stage. As the named stage is usually the main road, this can be beneficial to traffic flow in the region.

Two Stage Example:



Plan: {FA0}1, {FB0, FAB1}2
Explanation: Stage 1 = Force Controller Stage A
Stage 2 = Force Controller Stage B, or stay in Controller Stage A

Three Stage Example:



Plan: {FA0}1, {FB0, FAB1}2, {FC0, FAC1}3
Explanation: Stage 1 = Force Controller Stage A
Stage 2 = Force Controller Stage B, or stay in Controller Stage A
Stage 3 = Force Controller Stage C, or return to Controller Stage A

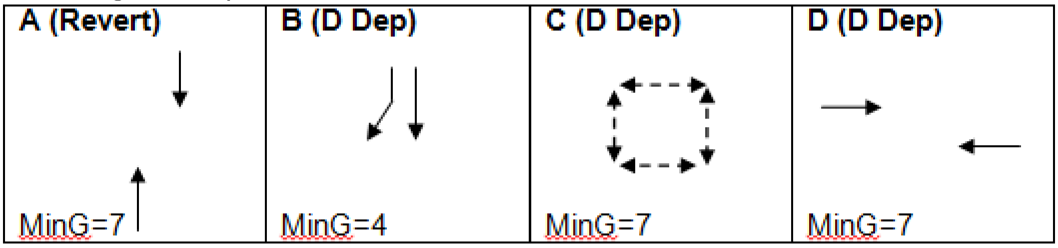
Where a junction has four stages or more, things are trickier, as any bonus time from demand dependent stages that haven't been called has to be dealt with differently. The options are:

- Remain on the previous stage
- Move to the next stage
- Send a demand, to force the junction to run the un-demanded stage

If the alternative stage you enter into the plan line is demand dependent, and also not demanded, then the controller will be unable to obey the stage change instruction and this will cause a plan compliance fault. The site will isolate from UTC control, unless a demand for the stage is also sent by UTC. It is therefore necessary to consider carefully how to build a plan line that will work at all times, whilst maintaining efficiency for the site. This means that staging order and the number of stages need to be carefully considered.

The below example shows the kind of issues that can arise:

Four Stage Example:



Plan: {FA0}1, {FB0, FAB1}2, {FD0+DD}3, {FD, FAD1}4

Explanation: Stage 1 = Force Controller Stage A
Stage 2 = Force Controller Stage B, or stay in Controller Stage A
Stage 3 = Force Controller Stage D, with UTC demand.
Stage 4 = Force Controller Stage C, or return to Controller Stage A

The staging order in UTC is more efficient than the controller staging order as it allows the traffic stage to be forced, and the pedestrian stage to act in the usual demand dependent way.

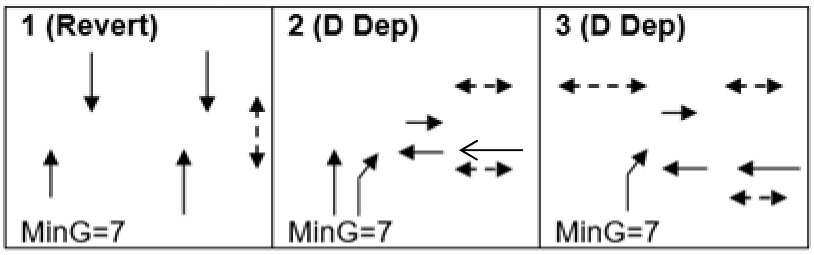
The order of stages chosen for SCOOT sites is important and needs to be carefully considered.

Prohibited Stage Changes

Prohibited and via moves make it more difficult to build plan lines that remain compliant at all times, as demand dependent stages failing to appear can lead to prohibited moves being requested by the plan line. Careful checking of the plan lines is needed to ensure that whether or not demand dependent stages are called, the plans are always able to run. The more banned and via moves there are, the more difficult this becomes.

Fixed Length Stages

The SCOOT model makes its stage change decision four second before the end of the stage, and will either retain, advance or retard the stage length. If the link in question terminates in a fixed length stage, then the SCOOT optimiser cannot change the stage length, so the link cannot be optimised. Therefore a staging order must be selected where no SCOOT links terminate in a fixed length stage. An example of where this has happened is shown below:



In this example, stage 3 contains an exit pedestrian crossing, which causes the stage to be a fixed length stage. However, as the site runs under SCOOT control and both the right turn and the westbound movement terminate in stage 3, this makes it impossible to optimise their stage lengths. Therefore when running under SCOOT control, the following staging order is used:

Plan: {FA0}1, {FC0, FAC1}2, {FB, FAB}3

Explanation: Stage 1 = Force Controller Stage A
Stage 2 = Force Controller Stage C, or stay in Controller Stage A
Stage 3 = Force Controller Stage B, or return to Controller Stage A

All Red Stages

All red stages can be used to make it possible for the junction to move through a prohibited stage change, by going via an all red stage. The all red stages can be set up in the controller either with or without a UTC stage confirm bit.

Where a stage confirm bit is present, the all red stage and it's timing information needs to be entered into the UTC system, and the stage needs to be included in the SCOOT plan line to prevent plan compliance faults from occurring when an all red reply bit appears.

Where an all red stage reply bit is not included, the UTC system will see the all red stage as an inter-stage, which needs to be accommodated within the UTC timing data, again, to prevent plan compliance issues.

It is common to base the decision to include a stage reply bit for the all red stage on whether the site dwells on the all red stage for long periods. This is because sites with no all red stage reply bit, that dwell on an all red stage will isolate from UTC control as UTC will see the site as stuck in inter-stage.

Alternate Staging

Where a junction is programmed with alternate staging, this can be problematic for SCOOT. Alternates can be set up so the junction will run one of two stages based on conditions within the controller, but these can be set up to reply either under one junction reply bit, or they each have their own junction reply bits. Both can be accommodated in SCOOT, but need to be set up carefully.

Where a single reply bit is used for both alternates, the SCOOT model may think a SCOOT link has been green during a stage when it didn't run. This is problematic when validating the links and causes the SCOOT model to be very inaccurate. In this situation, it is best to have a dedicated reply bit for each stage.

Where each alternate has its own stage reply bit, the building of plan lines can be problematic, as they need to be complex and often will miss out some stages entirely. Furthermore, this can be problematic in the TMS SCOOT system, as only two stage force bits can be sent in each stage for simple plan lines (three where relaxed plan checking is used), which makes it difficult if both alternates are demand dependent.

<u>Issues with Variable Inter-stages</u>

In order for SCOOT to work effectively, the model needs to know exactly how much green the link is getting and when the effective green will start and end.

To derive this information, the UTC system receives a green confirm bit from the junction. However, the green confirm drops at the end of the preceding stage, as soon as the first phase in that stage loses green. The green confirm for the next stage will not appear until all phases in the next stage have gained green. Not all phases gain or lose green together, due to varying inter-greens or phase delays, etc, so an adjustment is needed to the inter-stage value for each link, in order to obtain the correct effective green duration for each link. This is done by entering a start and end lag into the model for each SCOOT link.

These start and end lag values are fixed, which makes it very difficult to accommodate variable inter-stages. (Variable inter-stage modelling does exist in SCOOT, but its effectiveness is limited). Where the junction is using features such as on-crossing extensions, all red extensions, SDE or red lamp monitoring additional inter-greens, the inter-stage will be variable. SCOOT will be unable to model the link as accurately, due to the variability of the effective green time.

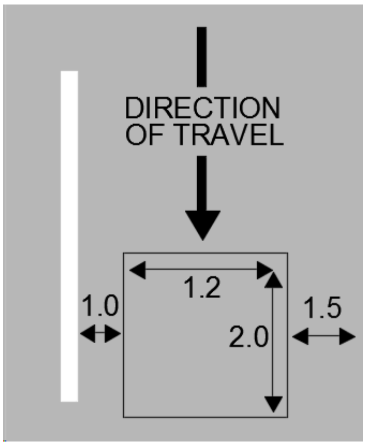
When designing a junction which will operate under SCOOT control, the designer needs to weigh up the importance of using features that cause variable inter-stages, against the need for the SCOOT model to accurately model the link. The decision made will depend on factors such as:

- How busy is the junction? Where it is extremely busy, features such as on-crossing or all red extensions will allow the designer to squeeze a bit more capacity out of the junction.
- How much do offsets matter? If the SCOOT model cannot accurately predict the start of stage, the offsets will be slightly incorrect, which will have a detrimental impact on junction capacity. This needs to be weighed up against the capacity increase caused by the feature.
- Does it matter if stages are run for too long? Where variable inter-stages cause quiet side roads, or pedestrian movements to run for longer than necessary, this can be detrimental to the operation of the site. But if the additional time can be added to the main or busier stages, this can mean the impact is minimal.

SCOOT Detection: Positioning SCOOT Detection

When a junction is designed, the SCOOT engineer must decide where to position the SCOOT detectors. A SCOOT detector is usually required for each separately signalled approach to the junction and sometimes on the exit lane to model traffic leaving the junction, if there are exit blocking issues at peak times.

SCOOT detectors are traditionally inductive loops, 2 metres long in direction of travel, and not less than 1.2 metres wide. It is recommended that they should be cut 1 metre from the centre line, and 1.5 metres from the kerb. For multi-lane approaches, there should be a minimum of 2 metres between loops. It is also possible to use Magnetometers or Above Ground visual detectors, configured for similar sized detection zones.



The detectors are monitored 4 times a second and the information is sent back to the SCOOT system in ¼ second increments showing detector presence or absence. This data is converted by the SCOOT system, into Link Profile Units (LPU's) using as linear discounted occupancy method. This then provides the traffic demand data used by the SCOOT model for the link.

For optimum operation, the detector should be positioned as follows:

- Where vehicles on that approach cannot miss it, and where vehicles on other approaches cannot clip it.
- There should be no significant sinks or sources (i.e., side roads) between the detector and stop-line (contributing more than 10% of traffic to the link), especially if the traffic flow is very variable on the sink/ source.
- For multi-lane approaches, one loop should cover no more than 2 lanes.
- The cable run between the loop and detector pack should ideally be no more than 150 metres.

- The SCOOT model needs time to make its calculation, so the detector is recommended to be no less than 6 seconds journey time from the stop-line. The optimum is 8-15 seconds, or on the exit from the next junction upstream if it is reasonably close.
- There should be a consistent journey time between the detector and stop-line. So the loop should not be positioned where traffic flow is often disrupted, such as where on-street parking or bus stops affect the journey time.
- SCOOT detectors are often positioned around 100 metres from the stop-line, however as detectors should be positioned where traffic is normally free-flowing (except in very congested conditions), this should be increased where there is persistent queuing. Effectively, traffic should only queue onto the detector at the height of the peak. This is because the SCOOT model measures congestion on the detector and uses this as a multiplier to increase green time on specific approaches based on queue lengths.

The following process will assist an engineer to position the SCOOT loops at a junction:
1) The SCOOT engineer must consider how the SCOOT model will work, by deciding what links will be set up for the junction.
2) Once this is decided, the engineer can then work out which approaches and exits will need detection.
3) Then the engineer can decide where the detectors should be positioned on each of the approaches, bearing in mind the issues described above.

SCOOT Detection: Where Normal Detectors can't be Installed

If a traffic movement has very poor lane discipline, or a very short flare lane, it may not be possible to position a detector on the link in the usual way. In these instances, historic detection may be used. This is where the loop is positioned downstream of the junction, rather than upstream. These loops are not as effective as normal links because they cannot measure congestion or effectively determine appropriate offsets between sets of signals. They operate by measuring how the effective green time on the link is used by the traffic, and generating a Saturation value for the previous cycle, which is then used to inform the stage length for the current cycle.

They are usually recommended only where normal detection cannot be used. There are two types of detector that are available in SCOOT and the following sections details where they may be needed.

Filter Detectors

These detectors are positioned in front of the stop-line and an average journey time is entered for the link, giving the journey time from the stop-line to the detector. The SCOOT model then only looks at the detector during the effective green period, minus the journey time. The system then calculates the saturation value from the detector data and uses this to determine the appropriate stage length.

Filter detectors need a consistent journey time between the stop-line and detector and this does need to be a relatively short journey time. It is also important that exit blocking does not cause the detector to have traffic queued over it regularly, as this prevents the model from calculating the Saturation value effectively.

As the detector is positioned in front of the stop-line, it cannot measure congestion in the traditional sense, and this makes it difficult for the SCOOT model to bias towards Filter approaches during congested conditions, as a Congestion Importance Factor (CGIF) cannot be used. For this reason, Filters are not usually recommended on main road movements.

However, the SCOOT system does now include a facility to mimic the Congestion Importance Factor (CGIF), making it possible to bias the SCOOT model towards increasing the stage length on Filter links during congested periods. This has facilitated the use of Filter detection in a wider range of contexts.

The command needed to set this up are:
Filter Saturation (FSAT/ FWSA): This parameter specifies a Saturation level above which you want the SCOOT model to begin biasing towards this approach.
Filter Multiplier (FMUL/FWMU): This parameter specifies how strongly you want the SCOOT model to bias towards the approach when it is above the specified Saturation value.

Stop Line Detectors

SCOOT Stop-line detectors can be positioned at the stop line or up to 20 metres upstream of it. In order to set these detectors up, the journey time must be set to zero.

The detectors work in the following manner. During the first 6 seconds of effective green, the SCOOT model assigns an average LPU value to any vehicles detected, to reduce the impact of the slow moving traffic on the model. After the first 6 seconds, the model assesses the usage of the green time to determine the level of saturation. The Saturation value calculated in the cycle is then used to help determine the stage length for the next cycle.

As with Filter detectors, they cannot model congestion, so cannot use this to increase green during congested condition. However, unlike Filters, there is no alternative facility available. For this reason, stop-line detection operates best on side roads, or less important movements, as it will not increase green as effectively during congested conditions. However, the use of stop-line detection is of value where the cost of ducting is high, and you need detection on side roads, right turns or similar minor movements.

Stop-line detectors installed for SCOOT, MOVA or VA can be used as SCOOT stop-line detectors. VA stop-line detectors are normally placed at 2 metres from the stop-line and are cut in a very similar way to SCOOT stop-line detectors.

To use a VA stop-line detector as a SCOOT detector, the TOPAS2500 configuration/ O.T.U configuration needs to be written in such a way that the VA detectors you want to use are available in the configuration as SCOOT detectors as well as VA detectors. For a Siemens configuration, this means adding the detectors to the Serial MOVA page, then adding the required detectors to the O.T.U configuration. Alternatively with Siemens controllers, if dealing with a faulty detector that there is no budget to re-cut, you can use the 'IOA' command to allocate the detector you wish to use as a substitute across to the input for the SCOOT detector that has failed. With Dynniq PTC-1's, the detectors need to be added to the TOPAS2500 configurations at design stage. With Telent Optimas, any detector can be picked up for use as a SCOOT detector by selecting it in the outstation configuration pages.

This is usually very cost effective where stop-line loops are required, and can save money as there is no need to duct or cut additional detectors.

SCOOT Detection: Setting up 'Spare' Detectors

In the current climate, many local authorities are in the position that they can obtain capital funding for major schemes, but revenue budget for maintenance can be problematic. For this reason, it is worth configuring as many 'spare' detectors for the SCOOT model as possible when the scheme is built.

Many other types of detector can be used as SCOOT detectors, and provided they are available to the UTC system, they can be used as a fall-back option, if the normal SCOOT detector has failed and there is no budget for the replacement of the detector.

For this reason, it is recommended that the following detector types be set up as SCOOT detectors in the junction configurations when they are created.

- MOVA Detectors
  MOVA IN detectors work well as SCOOT detectors, as they are often cut in roughly the right location and are a similar dimension to a normal SCOOT detector.
- SDE/ SA Assessors
  SDE/ SA detectors are very effective as SCOOT detectors. They are cut in a very similar way to SCOOT detectors, and are positioned at a good distance from the stop-line for SCOOT purposes.
- MOVA/ VA Stop-line Detectors
  MOVA or VA stop-line detectors can be used as a SCOOT detector, as described above.

For all of these detection types, if they are added to the TOPAS2500 configuration, they can be picked up and used by the SCOOT engineer when needed. The configuration of these detectors at design stage provides a simple and cost effective method to dealing with detector faults over the life of the scheme.

SCOOT Junctions: Conclusions

When designing a site to operate under SCOOT control, it is important to consider the following:

- Cycle Times: Can the junction work with the surrounding junctions in terms of cycle time?
- Offsets: Where multiple offsets are needed at once, the model may struggle to accommodate this. Is this an issue with this junction?
- Proximity: Is the proximity to surrounding junctions going to cause a problem in terms of maximum possible cycle time?
- Staging Order: Is this appropriate for SCOOT in terms of number of stages, staging order, prohibited moves, fixed length stages, alternates and all red stages
- Are the variable inter-stages proposed suitable?
- Are the SCOOT detectors correctly positioned?
- Where the positioning of normal SCOOT detectors is not possible, are historic detection options being used?
- Are alternative/ spare detectors being set up?

As a general rule of thumb, SCOOT is best suited to closely associated, busy urban networks where good offsets between sets of traffic signals are needed to get the most from the network. SCOOT will struggle to work well in situations where the cycle time needed by a SCOOT junction is significantly different than that of closely associated junctions. Also, it will struggle where the site has 4 or more stages and the demand dependent stages regularly aren't called in every cycle. During quieter times, this will seem slow to react and may give rise to complaints.

Designing the junction with the above principles in mind will maximise the efficiency of the junction as it operates within the wider network.

Traffic Signal Symposium 2020

Session Two

Paper TRL Software UTC Powered by SCOOT 7

By Subu Kamal - TRL and Hannah Tune - TFGM

Opening up SCOOT® data

By Subu Kamal, Mark Crabtree (TRL Software) and Hannah Tune (TfGM)

TRL Software Limited

1 Need for project

Technology continues to advance and with it an increasing amount of data is potentially available via a multitude of sources. This includes data about the movement of people using the transport network. The uses to which the data can be put, particularly when combining sources, is only just starting to be explored.

Technology is allowing SCOOT® messages to be made available in a more usable format. The SCOOT® algorithms take data from detectors on street and turns it into a model of traffic movements. The data is used directly to optimise the signal timings for minimum delay. The SCOOT® messages exist to allow operation to be inspected and tuned to obtain maximum benefits. Before now the messages have been viewable only by the owners of the installed instances of SCOOT®. Now, TRL Software has produced a cloud hosted SCOOT® UTC which, amongst other benefits, allows the SCOOT® messages to be made available to anyone (who is granted access).

There is a wealth of data within the SCOOT®-UTC system that could be made available for other purposes. Historically, availability of this data has been limited by the at-market solutions which have been selective in what data can be presented and readily accessed. Opening up the SCOOT® messages creates a unique opportunity for Greater Manchester digital eco-system to create new innovative services.

2 TfGM background

With 2,7M inhabitants, and an area of 1,276 Km^2, Greater Manchester has more than 5,6 million journeys across the transport network each day, equating to over 2.1 billion journeys every year, 268 million of which are made by public transport modes. TfGM aim to keep the city-region moving and growing, working hard to make travel easier through a better-connected Greater Manchester. This includes encouraging sustainable transport modes. However, the high use and dependency on private motorised vehicles for journeys as short as 1km results in congested urban centres and key route networks. This contributes to the deterioration of air quality which, in turn, costs businesses in Greater Manchester £1.3 billion. Therefore, resilience and reliability are the most pressing issues of existing and future transport in GM.

The current network is liable to congestion and delays, public transport overcrowding. These delays are caused by excessive private car use compounded with constraints on the existing highway infrastructure. TfGM therefore strive to have an efficient multimodal transport network, balancing the requirements of all road users, bus, metrolink, cycle and pedestrian. When safety is included, managing the traffic signal network can be extremely difficult.

2.1 Aims for ITS and Highway efficiency:

The development of new technology, traffic management systems and ways of working help TfGM to investigate the best approach for improving the transport system for all. The work with TRL has allowed use of the open standards to extract network data more easily, which can be used for:

- Analysis of junction performance,
- Investigation into use cases around connected vehicles,
- Investigation into how we better incorporate active travel into junction operation.

The benefit to TfGM of the TRL SCOOT® UTC and its basis in open standards is that it allows TfGM to make the best use of our existing assets and data which, in turn, can be utilised to improve congestion and delay. The integration of third-party data through open standards also presents a substantial benefit and a move towards easier integration and interoperability.

Engaging with third parties who can make use of the data and improve customer information which leads to improved customer experience across journeys for all modes and we continue to work in this area to encourage utilisation of the data.

2.2 TfGM Infrastructure:

Greater Manchester currently utilises existing sensing infrastructure for transport monitoring, this being: automatic traffic counters (flow and classification), CCTV, a network of Bluetooth sensor, video analytics sensors (150 approx.), as well as third party data sources such as floating car data for example Waze for cities data, allowing us to plan operationally and strategically.

2.3 Improvements for TfGM

Having greater access to the UTC SCOOT® data enhances this already substantial network of data. Making better use of these assets will allow a more coordinated and data driven approach to how we manage the network, addressing key issues such as:

- Identification of congestion hotspots – poor junction performance and junction design – improved safety if addressed
- Improving air quality – by reducing congestion
- Encouraging sustainable transport modes through better integration with the traffic signal control system
- Looking to the future and opportunities for connected vehicle – through investigation and trial of GLOSA

3 TRL Software UTC, Powered by SCOOT® 7

3.1 Why open up the data?

Traffic control and network management is a data driven process. In adopting an open data approach the benefits expected are bidirectional, with not only the authority enabling access to data previously kept behind a walled garden, but creating the opportunity to receive new and novel data which in turn has the potential to benefit the operational and strategic direction of network and urban management.

TRL Software Limited have been developing a UTC system that includes SCOOT® 7.0, known as the TRL Software UTC Powered by SCOOT® 7. The wealth of data that is produced by SCOOT® and the UTC hitherto has not always been easily available. A unique feature of TRL's SCOOT® UTC will be that any of the data it produces can be made available either offline or in real time (as SCOOT® runs).

Opening up the data creates a social contract through a sharing economy of data exchange; this would reduce reliance on third party data aggregation services which can be prohibitively expensive, in addition to reducing the provision of on street physical detection infrastructure. Where these are direct costs which can be reduced, immediate savings can be realised as a prelude to gained value.

Transport technology industry has not significantly changed in terms of end user value. One of the key reasons for this is access to data previously kept behind a walled garden. TRL strongly believe that if *you want to disrupt an industry that has not changed, we should liberate the data*.

3.2 What the SCOOT® UTC offers

Designed and developed by teams highly experienced in working with the SCOOT® kernel and algorithms, TRL's SCOOT® UTC brings accessibility to all local authorities.

TRL inherently works to values and objectives designed to enhance the daily lives of road users and is committed to reducing total cost of ownership of the SCOOT® UTC. TRL are also involved in key aspects of future mobility in order to make the best use of new and emerging technological solutions to future transport issues.

The key objectives of TRL's SCOOT® UTC are:

- Technology agnostic - works with any signal controller and Outstation Transmission Units (OTU) from any signal controller manufacturer using standard UG405 protocols. Also compatible with any cloud service provider in any user selected regions.
- Makes use of SCOOT® version 7 which includes:
    - Manual triggering of gating.
    - Generalised recovery from LRT or bus priority activity;
    - Multiple split optimisation which improves the accuracy of the model and timings.
    - Green man period optimised to number of pedestrians;

  - Modelling link departures to help with optimisation in general, loop failure logic and to reduce detection requirements;
  - Cooperative signals data to provide road users with information that can help with their journey.
- SaaS:
  - subscription based;
  - no hardware dependencies;
  - vertical and horizontal scalability depending on user needs;
  - automatic updates for subscribers.
- Usability – completely browser based with modern user interface and functionality to make setting up and maintenance as easy as possible. Also available on mobile devices and through API's.

Development of the UTC is continuous, and many exciting developments are planned in addition to the features and functionality that are already present. This includes strategy management, interfacing with common databases and full cloud-based interfacing.

3.3 How it solves the problem.

Before now SCOOT® messages and data could be observed in real time by various means. However, the information was only visible through displaying the contents of the messages on screen and through ASTRID. TRL's SCOOT® UTC makes the data available in JSON format via APIs. This allows the data to be 'consumed' in a way that makes its use in external applications possible. This isn't to say the data is available to just anyone, users of the data would have to be granted access. But it allows the data to be used in a completely free and practical way.

The information is accessed via a standard developer portal provided by the host. The portal is designed to give access to the data contained in the SCOOT® messages to software developers. This allows the information to be used in whatever way the consumer of the data requires, including real time use as well as gathering historical information.

4 Implementing the SCOOT® UTC in Manchester

As part of DfT's funding competition 'Making better use of local authority transport data' Transport for Greater Manchester (TfGM) working with TRL Software has:

- Deployed TRL's 'Urban Traffic Control (UTC), powered by SCOOT® 7 at a network of signal-controlled junctions in Greater Manchester.
- Engaged with the Greater Manchester data community to better understand their needs, opening up data to a more user driven approach.
- Provided previously inaccessible or high cost SCOOT® UTC data via the TRL open data platform.

For the project that TRL has conducted with TfGM, the SCOOT® UTC was implemented on the A665 through Radcliffe to the north of Manchester City centre. This included six junctions and two pedestrian crossings. The network has operated in a remarkably trouble-free manner for several months including more recently when traffic volumes have begun to reach their pre-pandemic levels once more. TfGM were quickly assured about the ability of the SCOOT® UTC to work to their satisfaction, including the notification of faults. See Figure 1.

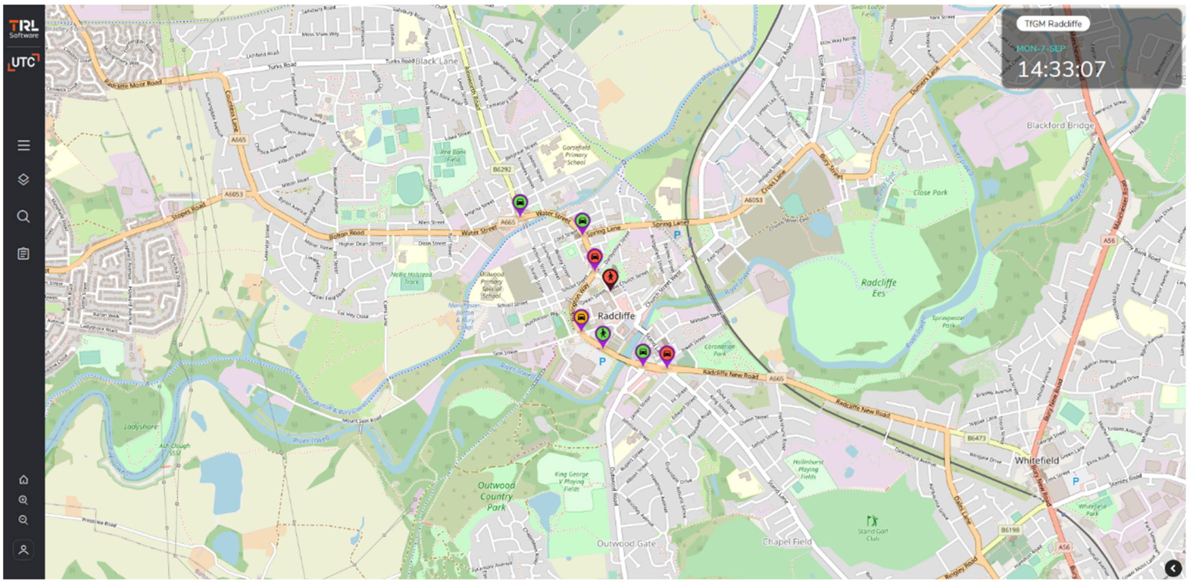


Figure 1: Radcliffe network as controlled by TRL's SCOOT® UTC

Initially the SCOOT® data made available in the project was limited to historical information. This was further limited to specific important SCOOT® messages to provide focussed information for interested parties to consider. Selected users were granted access to the data. All the data for the selected messages has been placed in the UTC database and made available to approved users. Potential uses for the data are for research, and to allow road use patterns to be investigated for example.

Live messages available via APIs, including the GLOSA-enabling X41 message have now been made available. The availability of the data allows possibilities around:

- enhanced information being made available to travellers,
- combining with other data sources to enhance the uses to which it can be put,
- Information that estimates when the signals will change, with tolerances (GLOSA).
- Informing drivers of the state of traffic signals to help them modify their approach to suit, which can lead to fuel consumption, emission and safety benefits;
- Strategy development from operational data that can lead to better incident mitigation
- Journey time and congestion information can help commercial partners such as WAZE.
- Enhanced fault management through third party applications having access to system data.

These are just some of the possibilities and app developers are at the beginning of their journey.

Continued project work streams are:

- Exploration of the application of C -ITS messages that can utilise the SCOOT® messages that are easily accessible, based on the open infrastructure within TRL's SCOOT® UTC.

- Continued investigation into the use case for data with academic partners University of Manchester and the Alan Turing Institute.

5 Conclusions

- The need for open data has been identified and the TRL SCOOT® UTC has been developed to open up SCOOT® data.
- TRL and TfGM embarked on a project to demonstrate the openness of the data, implementing the SCOOT® UTC on a selected part of the TfGM highway network. The implementation was on the A665 in Radcliffe, north of the city centre.
- The SCOOT® UTC has been successfully running for several months, including recently with traffic flows reaching their pre-pandemic levels once more.
- Historic SCOOT® data has been available to approved users, dating back to the implementation of the SCOOT® UTC.
- Live data has been made available more recently and the X41 data has been on particular interest.

Traffic Signal Symposium 2020

Session Two

Paper Improving Wolverhampton’s air quality through integrated data.

By Dr Shailesh Mistry - SWARCO and Paul Hudson NOW Wireless

IMPROVING WOLVERHAMPTON'S AIR QUALITY USING INTEGRATED DATA

DR SHAILESH MISTRY – SWARCO, PAUL HUDSON- NOW WIRELESS

JCT SYMPOSIUM 2020

Image: wmgrowth.com

1 What did we set out to do?

Wolverhampton wanted to take action and be a leader in regard to the public health issue that is air pollution. Working together with SWARCO and NOW Wireless, the City of Wolverhampton wanted to use data to enable them to make informed decisions around their traffic strategies and to see if they could resolve issues that the city faces.

According to the 2019 Air Quality Annual Status Report (ASR) carried out by City of Wolverhampton Council. 'The main air quality issues in Wolverhampton relate to emissions of nitrogen dioxide (NO2) from road traffic. The areas most affected are close to busy roads, junctions and parts of the city centre, particularly where the traffic is congested, the roads are narrow, or there is a high proportion of heavy goods vehicles (HGV's). Trend data over the last 15 years shows that levels of NO2 are going down. This has led to a significant drop in the number of locations where the annual mean air quality objective for NO2 of 40µg/m3 is being exceeded, however, there are still hot spot areas remaining. In 2018 the monitoring data identified 3 exceedances of the objective at locations where members of the public are likely to be exposed. These are on Broad Street in the City centre, on the A454 at Horsley Fields and on Lichfield street Bilston. The Department for Environment, Food and Rural Affairs (Defra) National PCM Model has also identified 4 other road links in Wolverhampton with projected exceedances of the NO2 objective up to 2021. Defra has required the council to carry out a feasibility study to deliver nitrogen dioxide concentration compliance in the shortest possible time on these road links.' [1]

2 What was the problem?

General

Pollution, be it noise, light, or air, is a recognised challenge to health and wellbeing in the urban and rural landscape. The problems have been most acutely experienced in urban areas where the migration of large numbers of the population to cities created crowded living conditions. As more data has become available, it appears the problem also affects anyone living and working near significant transport infrastructure. Some of the highest levels of pollutants are now being recorded in areas considered to be unaffected in the past. Ambient air pollution, and precisely a combination of small and fine particulate matter with traffic as the leading cause, is stated as the greatest risk to health – causing more than three million premature deaths yearly worldwide[2].

Why is urban pollution a cause for concern?

- 4.2 Million deaths linked to outdoor air pollution globally.[3]
- The cost of air pollution to the economy in England could reach £5.3 billion by 2035, unless action is taken[4].
- 49% of cities in high-income countries do not meet WHO air quality guidelines[2]

Vice versa, improvements in air quality have been directly linked to declines in the risk of stroke, heart disease, lung cancer, and chronic and acute respiratory diseases, including asthma.

The City of Wolverhampton Council, along with many others, are becoming more aware of the health issues for the public arising from over-exposure to high levels of pollutants including NO_2. The initial analysis done by the Council highlighted three or four areas of concern, where higher than normal levels of NO_2 could be identified. There was clearly a need for a more defined picture of what was happening on street with regards to NO_2 levels. Unfortunately, the traditional Chemiluminescent sensors can cost tens of thousands of pounds and a more cost-effective solution was needed. This solution needed to be accurate, and still provide data in real time (as opposed to diffusion tubes).

[1] City of Wolverhampton Council (February 2020), 2019 Air Quality Annual Status Report (ASR), Page 1
[2] World Health Organisation, (2018), WHO Global Ambient Air Quality Database (update 2018)
[3] World Health Organisation (2018), Ambient (outdoor) air pollution, Key Facts, paragraph 1
[4] Public Health England (2018), New tool calculates NHS and social care costs of air pollution, paragraph 1

3 Solution

The West Midlands (combined authority) already had the NOW Wireless secure carrier grade wireless network in use for their on-street applications and had been for over ten years, amounting to around 2,000 devices. This system provides a communication network that devices, such as Pollution Monitors, and Bluetooth Detectors, can utilise.

Having already carried out many successful trials of Bluetooth detectors and Pollution monitors across the UK with partners such as TfL and West Yorkshire, over a thousand have been installed and are a proven reliable solution.

The NOW Wireless in-house GUI, Senseview, allows clients to view data from the sensors in real time. The data can be exported, and API's allow the data to feed into numerous databases, and management software, including SWARCO's MyCity.

From the outset, SWARCO worked with Wolverhampton as a 'lighthouse customer'. Leading us along the journey to fulfil their technology needs and helping to shape the final solution they needed. Working directly with the key users within Wolverhampton we identified how the data sources were being used internally and what they wanted to gain from them. Using this as a guideline we made a wireframe of the potential solution so that the users could check the viability and highlight any deviations from the way they wanted to interact with it. This incremental process kept the key users engaged in the whole design and ensured the delivered product worked exactly as expected.

Running in parallel to this project, SWARCO had just opened the Solution Center, located in Berlin. The Solution Center is a hub for SWARCO software and platform development where we were working on a modular and flexible traffic management system. One that offers a new kind of flexibility compared to existing traffic management systems on the market, that are often under-utilised. This modern and scalable traffic management system became MyCity.

One of the core elements of MyCity is pollution reduction through enhancing traffic flows to reduce congestion and integrating with pollution monitors to create effective traffic strategies. The solution could provide the team at Wolverhampton with the ability not only to identify where air quality is below or within their planned thresholds, but also allow creation of dynamic strategies that can use the data collected and apply targeted actions before the level becomes a critical problem.

Source Data

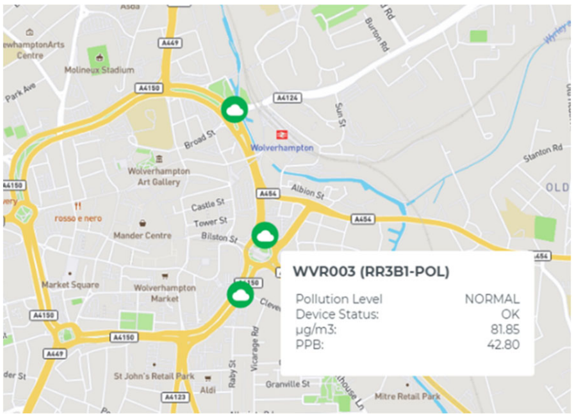
Having the right source data available is always key to making the best decisions. The MyCity platform had already been built to use a wide range of data sources and integrated easily with the NOW Wireless sensors and detectors.

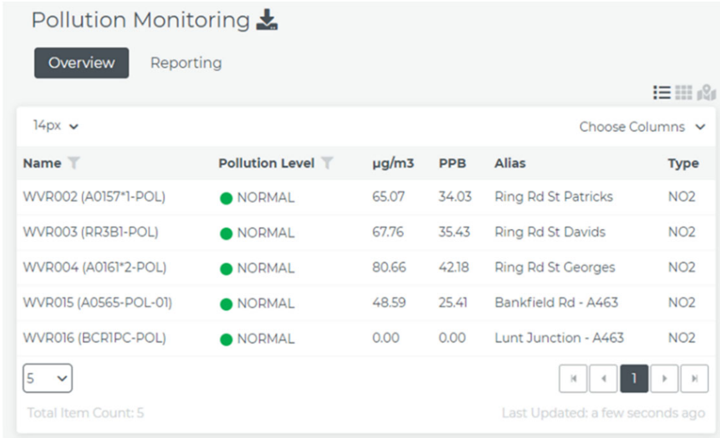
The NOW Wireless NO_2 detector is a cost-effective gas sensor for pollution detection. It is a highly sensitive detector, designed for mounting onto Traffic Lights and Lamp Columns. With alert functions and real time data for traffic management it provides a complete pollution solution.

The NO_2 detector samples the gas sensors every 60 seconds recording the data to a database. An average of the data is compared to pre-set values set on its web interface. If it detects a peak above a pre-set value (Web Interface setting), then it can send an email, trigger text messages or write to a URL with a data update. A web server allows the data to be extracted by a central computer in an asynchronous operation, this process can be Cloud or WAN based. This information is then fed into a database for analysis of Gas levels. Consequently, a real-time XML data feed is prepared, allowing information about pollution to be used in traffic modification of timing of signals or VMS sign warnings. The data from the sensor is also available directly from the NO_2 detector to the in-station or OTU via a simple web page.

Using CCTV and Video analytics, we can count and classify vehicles including any number of transport methods from bicycles to buses, and pedestrian counting.

Monitoring Air Quality
Once data has been collected and processed, the task of understanding how the city is being affected and where the hotspots are, was designed to be intuitive. The team working on the project at Wolverhampton could set their own threshold levels, and the data, status, and impact of changing conditions can be viewed in real-time.




Pollution Monitoring
Overview
Reporting
14px
Choose Columns

Name	Pollution Level	µg/m3	PPB	Alias	Type
WVR002 (A0157*1-POL)	NORMAL	65.07	34.03	Ring Rd St Patricks	NO2
WVR003 (RR3B1-POL)	NORMAL	67.76	35.43	Ring Rd St Davids	NO2
WVR004 (A0161*2-POL)	NORMAL	80.66	42.18	Ring Rd St Georges	NO2
WVR015 (A0565-POL-01)	NORMAL	48.59	25.41	Bankfield Rd - A463	NO2
WVR016 (BCR1PC-POL)	NORMAL	0.00	0.00	Lunt Junction - A463	NO2

Total Item Count: 5
Last Updated: a few seconds ago

Figures 1 & 2: MyCity screenshot showing a 'heatmap' of air quality at sensor locations - Green icons indicate air quality at acceptable levels

The large variety of data sets is visualised in real-time via different layers on top of the City's map utilising heat maps and performance-dependent colouring of the road network.
Users who want to take a more detailed look into it can also access a suite of pre-configured reports on the status of the data sources as well as the raw data. From these reports it is also possible to easily export the data for further separate analysis.

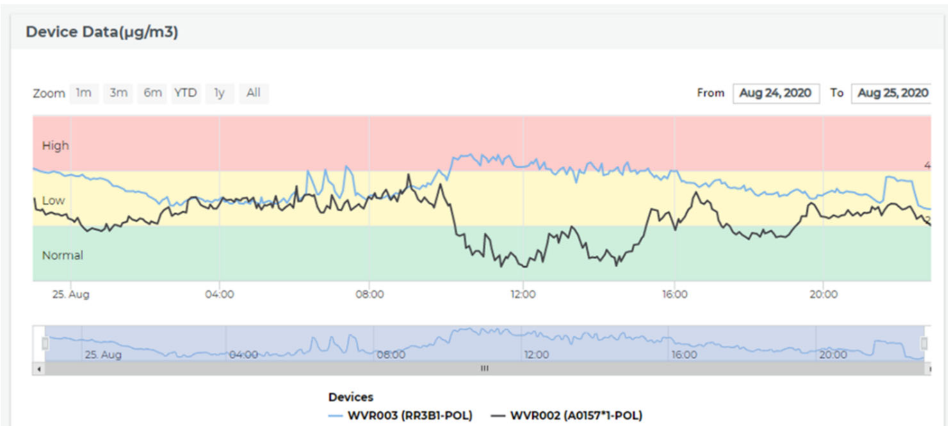


Figure 3: Report showing level of air pollutants at two locations over a 24-hour period

4 Challenges

During initial discussions with Wolverhampton we noted several key issues that they faced in their daily routines:

- Time/resources required for collecting data from numerous sources
- Human error introduced in collating the data into a coherent format
- Time/resources required for presenting the data for internal and external use

MyCity provided a way to automate the data collection across numerous feeds, processed all the inputs into a coherent format and then output reports that were suitable for internal and external users.

5 What was the result?

MyCity was updated to cater for all the data feeds from Now Wireless. Given the modular nature of the platform this means that any clients already working with these devices are now automatically catered for. The automated data collection significantly reduces the data collection time, eliminates the need for manual manipulation of the data and ensures the reliability of the stored results. Internal and external report generation is also automated thus eliminating the need to manually process data and simplifies the whole process to a button click.

Analysis

The data collected during the lockdown period from both an overview, and from individual sites shows a clear drop in Pollution Levels.

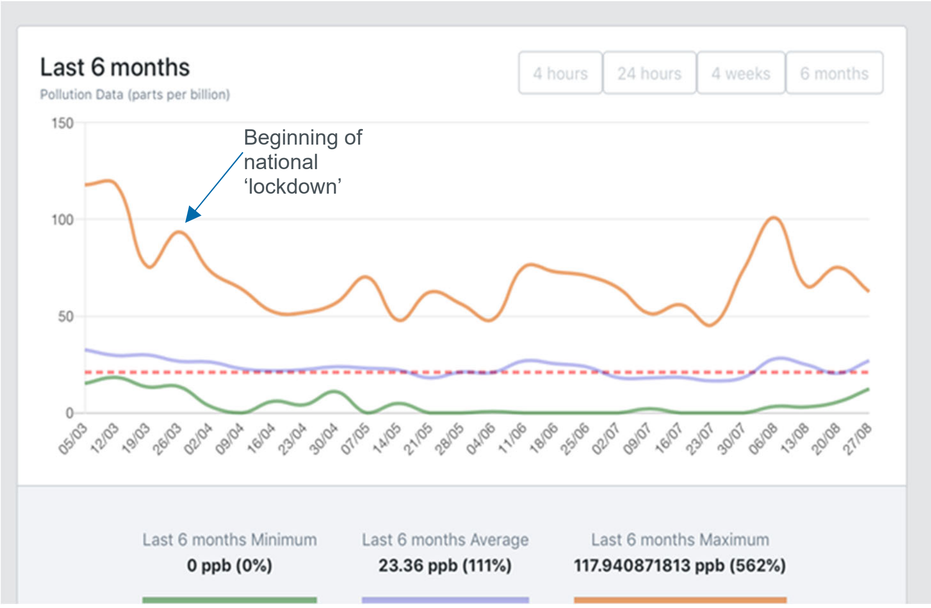


Figure 4: Report from Senseview displaying a significant drop in pollution at one location after the 'national lockdown' began.

Figure 5: Report from Senseview displaying the data for all locations over the last six months, again a drop can be seen at the point of 'lockdown'

As the lockdown eased, the pollution levels can be seen to increase. This trend was also replicated in the number of journeys taking place. Reducing over lockdown, only to start picking up again as it eases.

Next Steps

The City of Wolverhampton Council have installed around 70 Bluetooth detectors across both Wolverhampton and Walsall, with the aim to look at all routes on their network. More pollution monitors will also be added to the areas of concern initially, and then on a larger scale along significant routes in the area.

Through collaboration and integrating our data, we can improve the quality of the air in the critical areas around Wolverhampton and improve route performance across the whole city.

At every stage, any actions taken must be consistently monitored by the sensors to make sure we are moving in the right direction, and not making matters worse. The initial actions would be to change traffic plans (timings etc) and look at gating traffic outside the areas of concern. We would also inform drivers in several ways. By letting drivers know of the quickest routes or informing drivers of pollution levels, specifically around school environments to hopefully change driver behaviour and mindset. We would also look to inform drivers of the best time to travel by informing drivers at journey times through-out the day.

During the first phase of integration only a subset of the detection devices were integrated into MyCity, this included:

- •5 Pollution Sensors
- •72 Bluetooth Journey Time Sensors
- •28 Vehicle Counters

The feed data was sampled every 5 minutes which resulted in roughly 30K data points collected each day. The second phase of integration will bring in the remaining detectors giving a total 200 detection devices resulting in 60K data points per day and an overall 22M data points per year.

6 Future Use Cases

'Call for Action' notification
To make an impact the monitored levels need to inform targeted actions to actively reduce the level of air pollution in the city.

Whilst the monitoring aspect of MyCity gives users the ability to see what is happening at any moment in time, it is vital to use the information to take targeted, balanced actions if the air quality levels are to be restored to their acceptable levels. Wolverhampton will be able to use the Strategy Manager service to provide them with the ability to configure 'actions' that do just this. 'Actions' can be set-up to be automatically applied, thereby taking away the need for constant supervision.

'Actions' can also be set up to be presented as 'suggestions,' which are then presented through the user interface or can be distributed by email or text, before the user chooses the most suitable for manual deployment while monitoring the different data sets. Via user-configurable thresholds, the team will get notified when the air quality exceeds the defined level, via email and text message, so further actions such as road closures, rerouting traffic via variable message signs, or limiting access to certain vehicle classes can be implemented immediately, manually or automatically.

Reroute traffic
External pollution has a direct correlation with traffic volume and type of vehicles, so one of the first and most impacting factors that can be changed is to reduce the number of vehicles on the road. The Strategy Manager service is able to trigger new scenarios where traffic is steered away from highly congested areas by adjusting signal plans, displaying messages, and changing dynamic signs to restrict

access to specific areas either generally or for specific vehicle types (environmental badge or electric vehicles only etc.). Commuters travelling by car who have not yet made their way onto Wolverhampton's infrastructure inside of the ring-road can also be informed of the changes that have been made and be directed to Park & Ride services so that they can travel the last miles using other modes of transport. The dynamic component of the strategy manager then allows the city to apply different sets of actions as the air quality level improves, e.g., re-open areas to all traffic.

Adjust speed of traffic
Traffic speed and particularly unnecessary braking and acceleration is another factor recognised as being linked to pollution levels. Moving vehicles create higher levels of pollutants as speed increases, but they also have an impact when stationary as exhaust emissions concentrate around traffic queues. In urban areas moving vehicles help to disperse high levels of pollutants, but when traffic becomes stationary this effect is lost, and dangerous levels of pollutants quickly build up.

The ability to dynamically manage traffic speed can be a highly effective tool to make streets safer, specifically in times of an increasing share of vulnerable road users. Depending on the modality prioritisation, dynamic traffic management can also become one of the primary motivators for drivers to switch to other modes of transport.

Using the Strategy Manager, Wolverhampton will be able to smooth traffic flows which not only enhance the driver experience but also helps to minimise travel times and reduce emissions, prioritising the health of its residents. As air quality changes, traffic signal plans can be dynamically changed and with the introduction of variable speed limit signs on key routes drivers will be quickly advised of the most optimum speed to use to get to their destination, balancing emissions with time. In this specific use case, Variable Message Signs (VMS) will display a new speed limit with an optional warning messages until the air quality has dropped below the threshold.

Adjust traffic
Traffic signal coordination is vital for a reduced number of stops and emissions. Adaptive traffic control will handle coordination at a regional level and adapts local control to prevailing traffic conditions. The objective function of network-wide optimisation aims for an optimal flow ratio based on a utilised function for every scenario. In addition, rule-based decision making can be placed on a higher level to support signal plan selection based on emission levels.

Real-time data sharing
The combined Pollution Monitoring and Strategy Manager services are not just limited to managing systems that are directly supplied by SWARCO. There are a number of open API's available that provide the city with all the tools they need to also share the data collected, as shown with the integration with the NOW Wireless equipment.

7 Conclusion

The original challenge was to improve Wolverhampton's air quality using only existing street equipment. The solution has seamlessly integrated all of the existing data feeds into one platform to give a more coherent outlook on the whole problem and not just the sum of the parts. This collaboration has automated the data collection and collation process to reduce the time/resources required while also removing any inaccuracies incurred during the manual handling of data.

With a view to the future, the strategy manager will be used to define key performance indicators that can monitor the whole of Wolverhampton's traffic management infrastructure while multiple new strategies and scenarios are evaluated. The resulting information can be formatted for internal business processes and be made available to external customers for further analysis.

Traffic Signal Symposium 2020

Session Two

Paper Bus Priority in London – getting more out of what we have

By Mike Bloomfield and David Oram - TfL

Bus Priority in London – getting more out of what we have

Michael Bloomfield & David Oram
Transport for London

September 2020

EVERY JOURNEY MATTERS

Bus Priority in London – getting more out of what we have

Introduction

Transport for London (TfL) operates the most frequent and extensive bus network in the world with around 675 routes and 9,300 vehicles. This service is vital to the economic and social wellbeing of London with 2.32 billion bus journeys made in London last year.

Buses transport more people than any other public transport mode in London. They form key links to town centres and other destinations across the city and are one of the most efficient uses of road space, playing an important role in delivering the Heathy Streets Approach outlined in the Mayor's Transport Strategy.

iBus transponder units were fitted on all London buses in 2009. Using GPS technology, this allowed TfL to know the exact location of each bus at all times. It also gave us the ability to provide bus priority at traffic signals (c.1900 locations). The iBus units communicate with Virtual Detector Points (VDPs) associated with traffic signals to help alter timings to favour a smooth journey for buses and minimise delay as much as possible.

Recent work in Network Performance Delivery has explored how we can increase levels of Bus Priority on London's network by utilising equipment in innovative ways and analysing data on the UTC system never previously considered.

Bus Priority in London and the UTC System

Transport for London's Network Performance Delivery (NPD) team is responsible for setting up, operating and optimising London's traffic control system in order that the network suits everyone. A key part of this includes Bus Priority (BP) in SCOOT, known as PROMPT (**PR**iority and inf**O**r**M**atics for **P**ublic **T**ransport).

Bus Priority (BP) at junctions works by either extending the current green signal time at the end of a stage to allow a bus through (an "Extension"), or by shortening opposing stages to get the approach that the bus is on back to green in a shorter period of time (a "Recall").

At junctions where standard BP (SBP) is not suitable Differential Bus Priority (DBP) can be implemented. DBP uses bus schedule information and prioritises only delayed buses. This allows an increased amount of priority to be given to late buses.

Below is a summary of BP equipment and configuration in London (data taken from July 2020);

- 1909 sites with Bus Priority
- 1516 sites with BP on UTC
- 1155 on UTC running SBP
- 361 on UTC running DBP
- 393 sites with BP on VA
- 6134 VDPs (Virtual Detection Points)

The following three graphs give an overview of BP activity on the UTC system. Figure 1 represents the daily total of buses seen, and shows an increasing number from October 2018 to February 2020. This figure represents every time a bus is detected at a VDP by the UTC system.

Figure 1 – Daily total (average) of buses seen by the UTC System

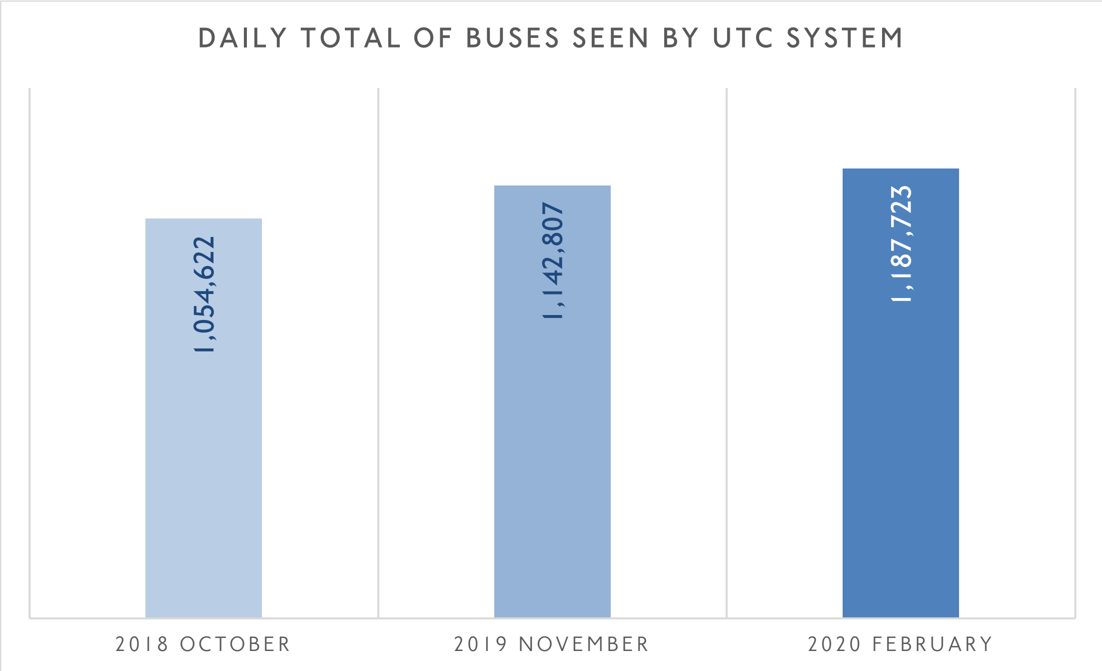
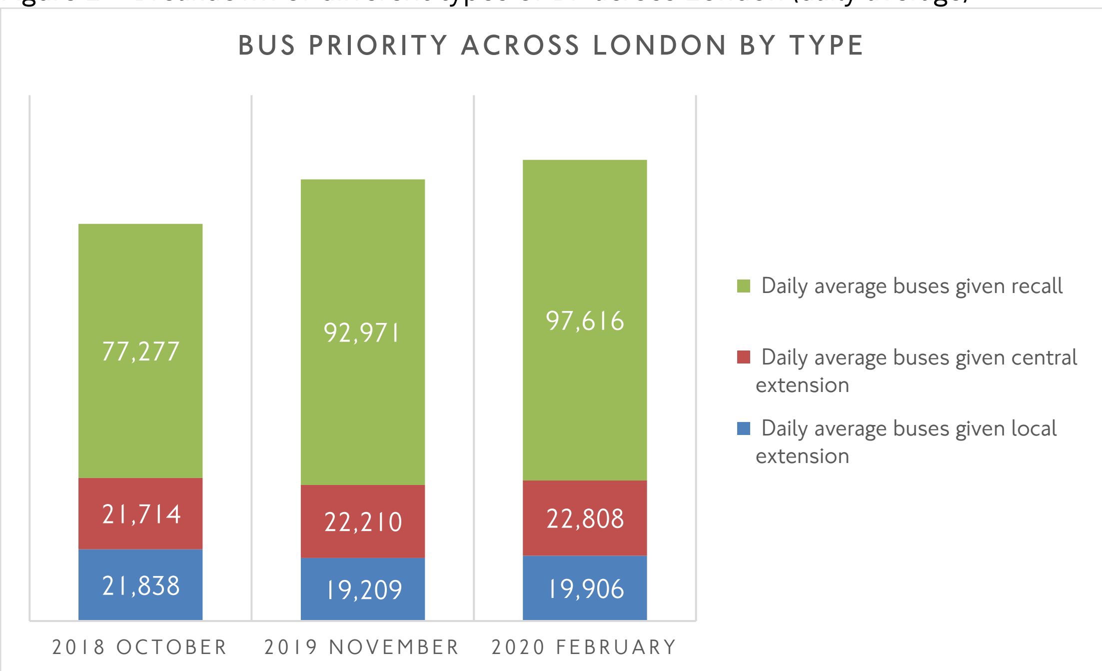


Figure 2 shows the breakdown of different types of BP granted at signals. Recalls comprise the bulk of BP activity, with Central and Local Extensions being similar in number. Extensions are rarer as a form of priority as the bus has to be approaching the signal in a smaller time "window" for this type of BP to be possible.

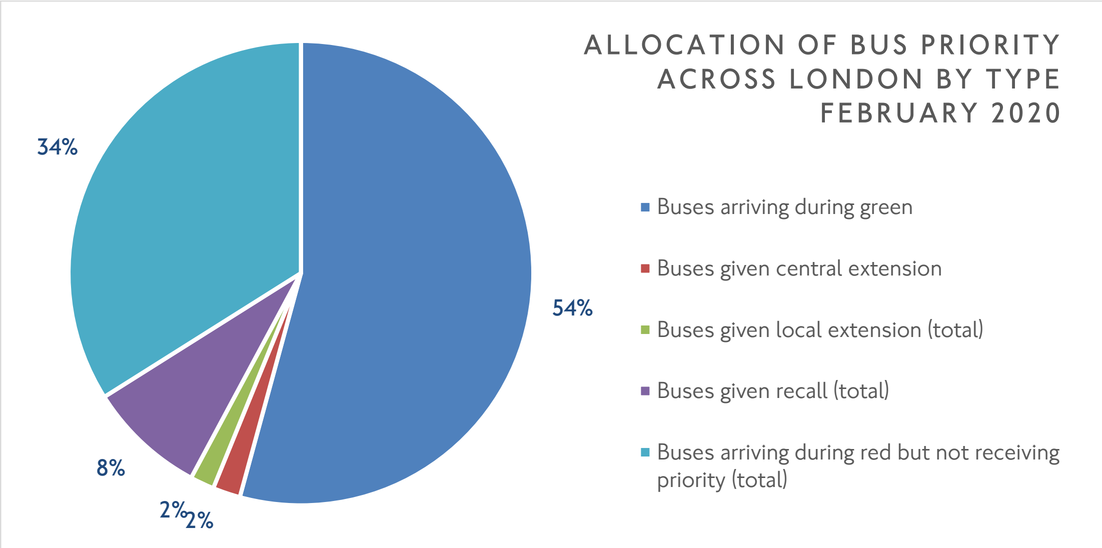
Figure 2 – Breakdown of different types of BP across London (daily average)



Both Figures 1 and 2 show increasing trends which is reflective of NPD's continued work to install and implement BP and make system changes to give as much priority to buses as possible. The innovative techniques described in this paper are helping to contribute to these trends.

Figure 3 shows data from February 2020 only, giving a percentage breakdown of BP activity for all buses detected. Over 50% of buses receive no priority as they arrive during green, and no priority is required. 34% of buses are detected but receive no priority, due to network and system constraints.

Figure 3 – Allocation of BP across London by type (February 2020)



Given that many junctions still do not operate BP, there are numerous locations where bus journey time improvements could be made. Unfortunately, due to limitations in BP hardware availability and funding, London's BP network is currently only being maintained, not expanded. It is for these reasons that the innovative techniques described in this paper have been explored and are now being implemented.

Innovative Techniques to Increase Levels of BP on the UTC System

1. **Moving existing VDPs to adjacent junctions**
   - **Camberwell Road, LB Southwark (J08/043 & J08/277)**

The first case study relates to moving VDPs between junctions to enable BP to function at a location that didn't previously have the capability.

Camberwell Road in the LB Southwark (see Figure 4) has 14 bus routes and serves as a key North-South public transport corridor. Within this UTC SCOOT region, J08/043 (Camberwell Road / Albany Road) operates BP, with 4 VDPs (see Figure 5) but J08/277 (Camberwell Road / Bethwin Road) to the south had no BP capability.

Figure 4 – Location map of J08/043 & J08/277

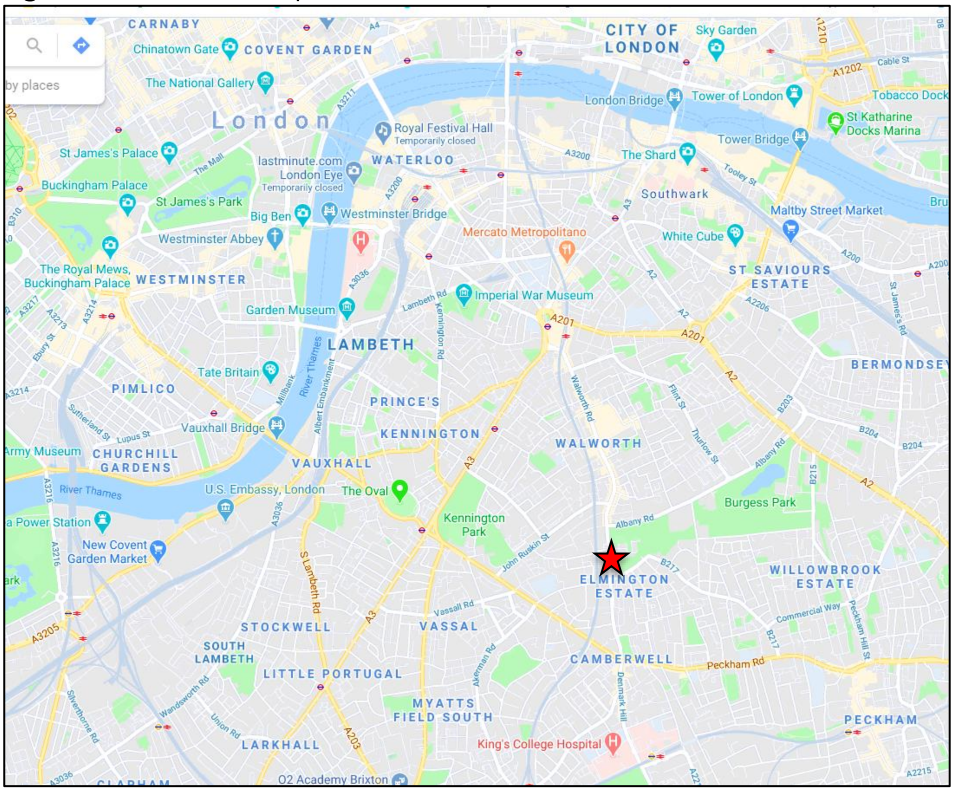


Figure 5 – J08/043, the 4 VDPs and giveway right turn movement for iSB3.

Of the 4 VDPs at J08/043, 2 of them monitor 14 routes each, whereas the other 2 monitor just one route each. Additionally, one of those (iSB3) monitors buses that immediately join a gap accepting right turn queue, making the bus difficult to precisely track and BP hard to grant accurately (see Figure 5). It was therefore concluded that two of these VDPs were underutilised and could be better used to give greater BP elsewhere.

Given the close proximity of J08/277, the clear line of sight, and the underused nature of 2 VDPs at J08/043, there was opportunity to reposition iSB1 & iSB3 to improve BP. iSB1 and iSB3 were therefore reassigned to 08/277 to the south to allow for BP to function there – where 14 routes travel North-South (see Figure 6).

Figure 6 – Updated located of VDPs, with two VDPs (*shown in blue*) moved to J08/277

Figure 7 shows the Before and After bus counts for iSB1 – previously only one route was detected, ranging from 2-5 buses per hour (and none overnight), whereas in the new location up to 70 buses per hour are detected, with detection across all 24hrs in the day. This clearly is a far better use of the VDP and more BP can be offered.

Figure 7 – Before & After bus counts on iSB1

Bus Counts For Detector B08/043/1

Hour Ending	Total Count	P0 Count	P1 Count	P2 Count	P3 Coun
01:00	2	0	0	2	
02:00	0	0	0	0	
03:00	0	0	0	0	
04:00	0	0	0	0	
05:00	0	0	0	0	
06:00	0	0	0	0	
07:00	0	0	0	0	
08:00	3	0	0	3	
09:00	2	0	0	2	
10:00	3	0	0	3	
11:00	3	0	0	3	
12:00	5	0	0	5	
13:00	3	0	0	3	
14:00	4	0	0	4	
15:00	4	0	0	4	
16:00	4	0	0	4	
17:00	4	0	0	4	

Bus Counts For Detector B08/043/1

Hour Ending	Total Count	P0 Count	P1 Count	P2 Count	P3 Coun
01:00	43	0	0	43	
02:00	18	0	0	18	
03:00	14	0	0	14	
04:00	14	0	0	14	
05:00	18	0	0	18	
06:00	34	0	0	34	
07:00	51	0	0	51	
08:00	68	0	0	68	
09:00	65	0	0	65	
10:00	67	0	0	67	
11:00	70	0	0	70	
12:00	68	0	0	68	
13:00	68	0	0	68	
14:00	68	0	0	68	
15:00	73	0	0	73	
16:00	67	0	0	67	
17:00	67	0	0	67	

Ordinarily, BP is configured on an individual site basis, but if sites are in close proximity, with good line of sight, equipment can be shared across multiple sites. This gives us the potential to increase the number of locations that have BP without the need for additional hardware. Also, there is potential to rationalise the existing equipment we have deployed and reallocate it to other suitable locations elsewhere that have no BP or aren't suitable for sharing with other sites.

2. Adding new detectors to an existing junction for use at an adjacent one

- **22/188 and 22/105 in Wimbledon TC**

The second case study focuses on adding new VDPs to a junction with BP, but using them for an adjacent junction.

Wimbledon Town Centre in the LB Merton (see Figure 8) has high concentration of traffic signals and 11 bus routes. Within this SCOOT region, J22/105 (Hartfield Road / Hartfield Crescent) operates BP, with 10 routes per hour and a suitable VDP. However, the upstream junction, J22/188 (Hartfield Road by Graham Road) had no BP configured (see Figure 9).

Figure 8 – Traffic signal installations in Wimbledon Town Centre

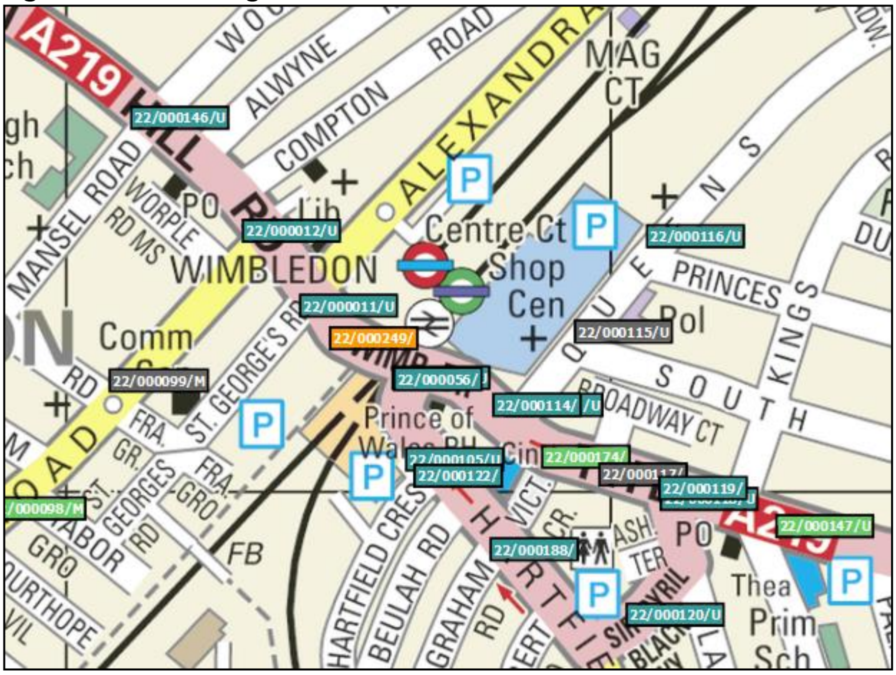


Figure 9 – Initial BP configuration at 22/105 – note one VDP on the approach to 22/105, none at 22/188

Similar to the first case study, 22/105 has excellent line of sight to 22/188 making the sharing of BP equipment a possibility. However, J22/105 only had one VDP configured, so rather than repurposing underutilised VDPs, new ones needed to be added. A new controller configuration (PROM) was created for this, with two new VDPs being added (iSB1 & iSB2), which did incur a small cost. Figure 10 shows where these new VDPs were positioned.

Figure 10 – Updated BP configuration at 22/105 – note two additional VDPs (*shown in blue*) on the approach to 22/188

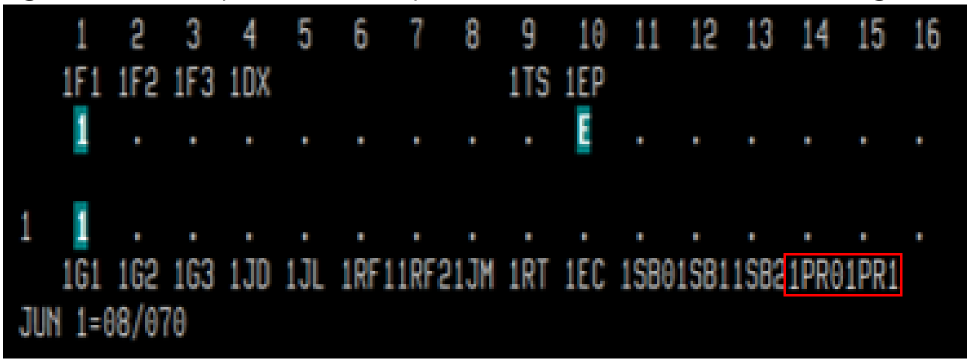
Prior to this change, 22/188 was not configured with bus priority, and buses that had stopped in the layby to board/alight passengers would have to wait for its next window of opportunity within the UTC SCOOT plan to re-join the one-way system. With new VDPs in position, BP was able to be setup, and priority granted to buses. UTC system messages run shortly afterwards for a day showed a total of 148 recalls for buses in the layby, with an average saving in delay of 20 seconds per bus.

As with the first case study, this technique allows us to increase our coverage of BP without the need for additional BP hardware. It has proven successful as a low cost solution to providing additional BP on the network.

3. Converting available bits on the UTC pattern to create new VDPs – Denmark Hill

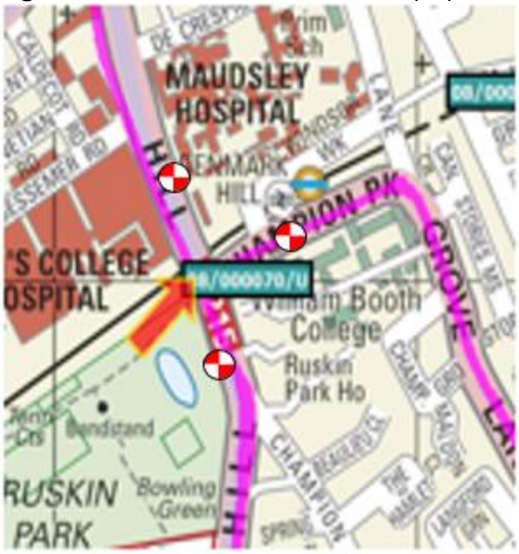
UTC bits patterns have been historically configured and future proofed with both SB (bus detection) bits as well as PR (Priority) bits (see Figure 11). SB bits are essential for BP at a junction, whereas PR bits are only required if a junction were to run Differential Bus Priority (DBP). Both SB and PR bits are similar in that they are both wired into the iBus unit and therefore already in the controller prom. Many locations in London do not require DBP, therefore there is an opportunity to convert not required PR bits into SB bits, giving greater BP possibilities at junctions that need additional VDPs. The following example expands upon this.

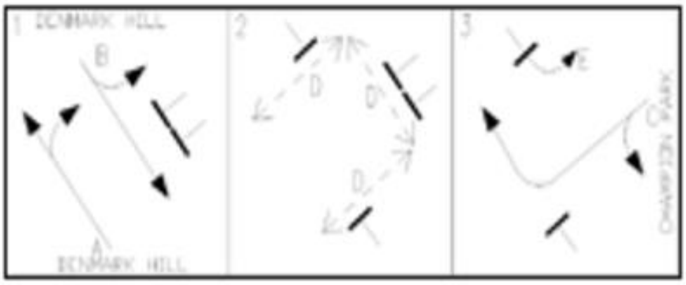
Figure 11 – Example of UTC bit pattern with both SB & PR bits configured



The junction of Denmark Hill / Champion park (J08/070) in LB Southwark has 10 bus routes, BP configured, and a single VDP on each approach (see Figure 12). However, southbound bus routes travel both straight ahead (southbound) and turn left on Champion Park. These two movements are represented by Phase B (in Stage 1) and Phase E (in Stage 3) (see Figure 12 for signal staging). Having only one VDP on this approach does not allow the unique identification of routes or movements. Therefore appropriate BP cannot be assigned accurately as SCOOT does not know what phase the bus will move in.

Figure 12 – J08/070 location map, position of VDPs and signal staging method of control





The solution to this problem is to create VDPs for each unique bus movement so SCOOT is able to accurately detect and model where buses are in the traffic queue. A new PROM with new VDPs could be added (as in Case Study 2), but this incurs a cost and delay. An alternative is to convert the unused PR bits already configured at J08/070 into new SB bits to allow VDPs to added. This can all be done in the BP configuration at a very low cost, and in a small amount of time. J08/070 does not meet the criteria for DBP given the low bus flows and relatively good junction capacity so in this example the loss of ability to run DBP was not a cause for concern. Figure 13 shows the updated UTC pattern once the PR bits were converted to a suitable SB bit. Figure 14 shows the new VDP added to the southbound approach.

Figure 13 – updated UTC bit pattern with PR bits converted to SB3

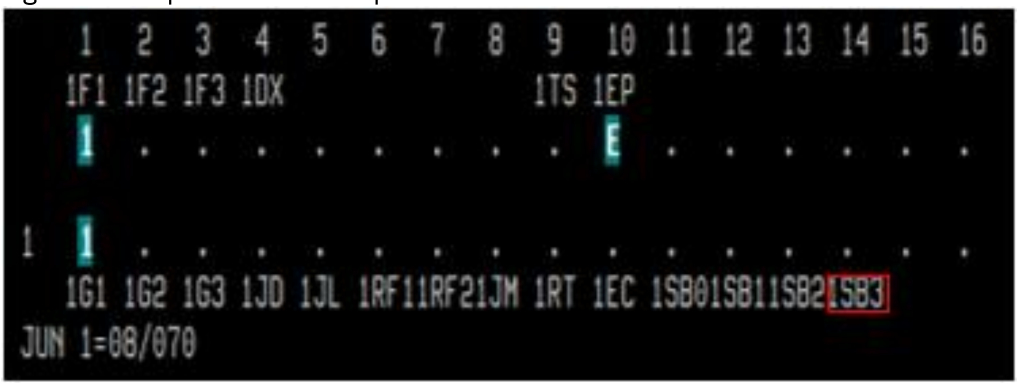
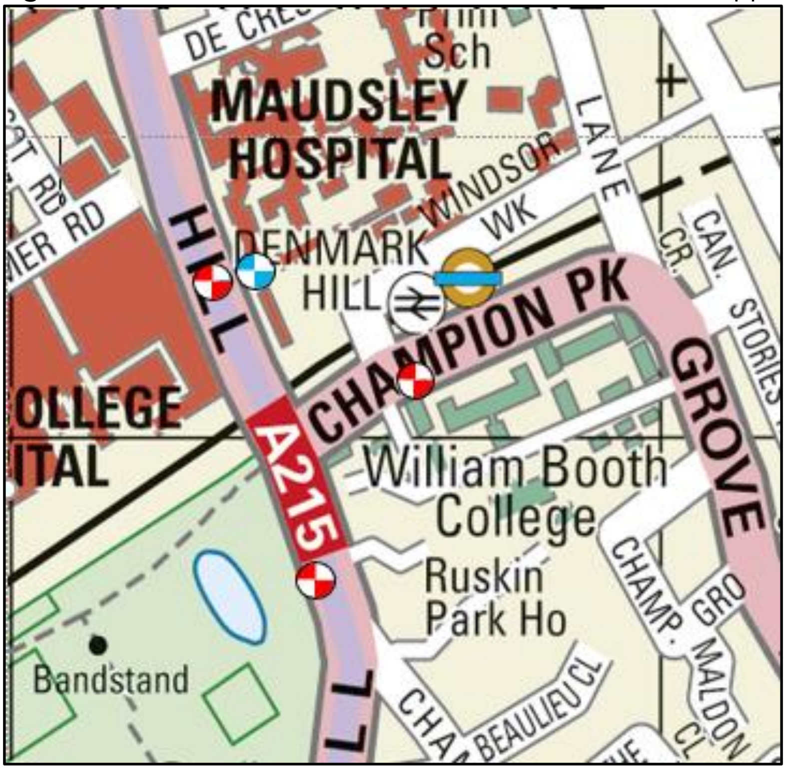
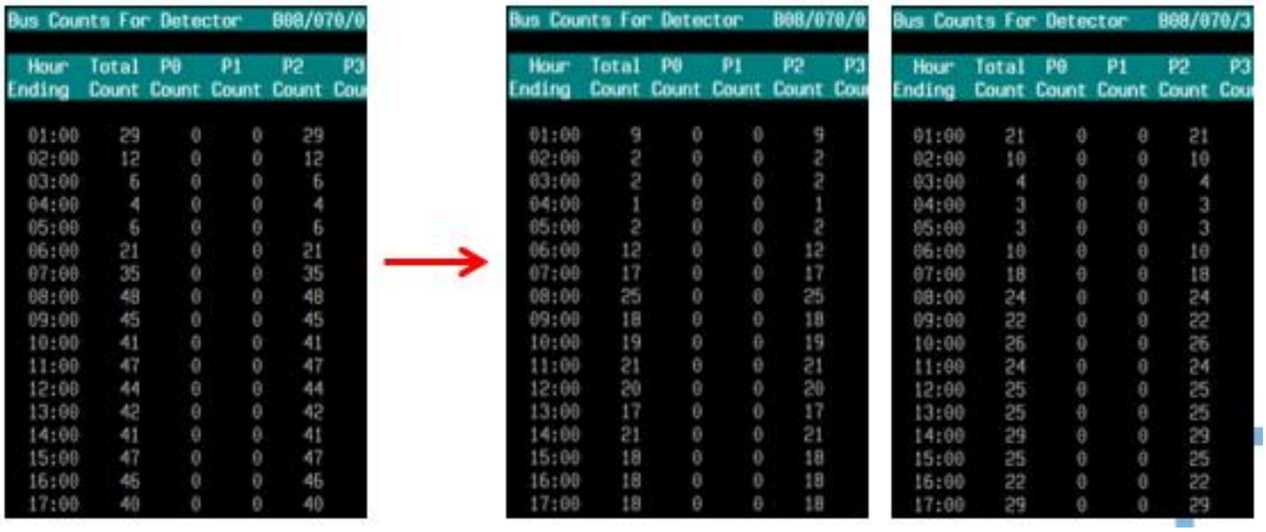


Figure 14 – J08/070 with two VDPs on the southbound approach, SB3 shown in blue



Once the PR bits were converted to a new SB bit (SB3), this could be linked to a new VDP on the southbound approach to J08/070. Unique bus movements could then be assigned to each VDP. Figure 15 shows the original and updated bus counts – previously multiple routes were captured at SB0, whereas now routes are uniquely captured on SB0 & SB3.

Figure 15 – Original and updated bus counts once bus routes were uniquely identified on the southbound approach to J08/070



Bus Counts For Detector 008/070/0

Hour Ending	Total Count	P0 Count	P1 Count	P2 Count	P3 Cou
01:00	29	0	0	29	
02:00	12	0	0	12	
03:00	6	0	0	6	
04:00	4	0	0	4	
05:00	6	0	0	6	
06:00	21	0	0	21	
07:00	35	0	0	35	
08:00	48	0	0	48	
09:00	45	0	0	45	
10:00	41	0	0	41	
11:00	47	0	0	47	
12:00	44	0	0	44	
13:00	42	0	0	42	
14:00	41	0	0	41	
15:00	47	0	0	47	
16:00	46	0	0	46	
17:00	40	0	0	40	

Bus Counts For Detector 008/070/0

Hour Ending	Total Count	P0 Count	P1 Count	P2 Count	P3 Cou
01:00	9	0	0	9	
02:00	2	0	0	2	
03:00	2	0	0	2	
04:00	1	0	0	1	
05:00	2	0	0	2	
06:00	12	0	0	12	
07:00	17	0	0	17	
08:00	25	0	0	25	
09:00	18	0	0	18	
10:00	19	0	0	19	
11:00	21	0	0	21	
12:00	20	0	0	20	
13:00	17	0	0	17	
14:00	21	0	0	21	
15:00	18	0	0	18	
16:00	18	0	0	18	
17:00	18	0	0	18	

Bus Counts For Detector 008/070/3

Hour Ending	Total Count	P0 Count	P1 Count	P2 Count	P3 Cou
01:00	21	0	0	21	
02:00	10	0	0	10	
03:00	4	0	0	4	
04:00	3	0	0	3	
05:00	3	0	0	3	
06:00	10	0	0	10	
07:00	18	0	0	18	
08:00	24	0	0	24	
09:00	22	0	0	22	
10:00	26	0	0	26	
11:00	24	0	0	24	
12:00	25	0	0	25	
13:00	25	0	0	25	
14:00	29	0	0	29	
15:00	25	0	0	25	
16:00	22	0	0	22	
17:00	29	0	0	29	

As can be seen in Figure 15, routes are now separately detected and can be assigned accurate BP based on what movement they are undertaking.

Prior to this change being made, BP was inhibited on this approach (due to the inability of SCOOT being able to accurately model buses and assign priority). However, since the change was implemented, BP was enabled and over a typical 24hr period 70 BP recalls were permitted, and over 30 extensions were granted.

4. High Priority Routes – PR bit manipulation

DBP uses bus schedule information to determine whether a bus is early, on time or late. Depending on its status, a bus will be assigned a combination of PR bit returns which then allows PROMPT to make a BP decision.

When configuring BP in the bus configuration routes are coded and standard priority levels set. The configuration of PR0/PR1reply and the associated lateness of the bus has been standardised and below are the four possible combinations once a bus is detected:

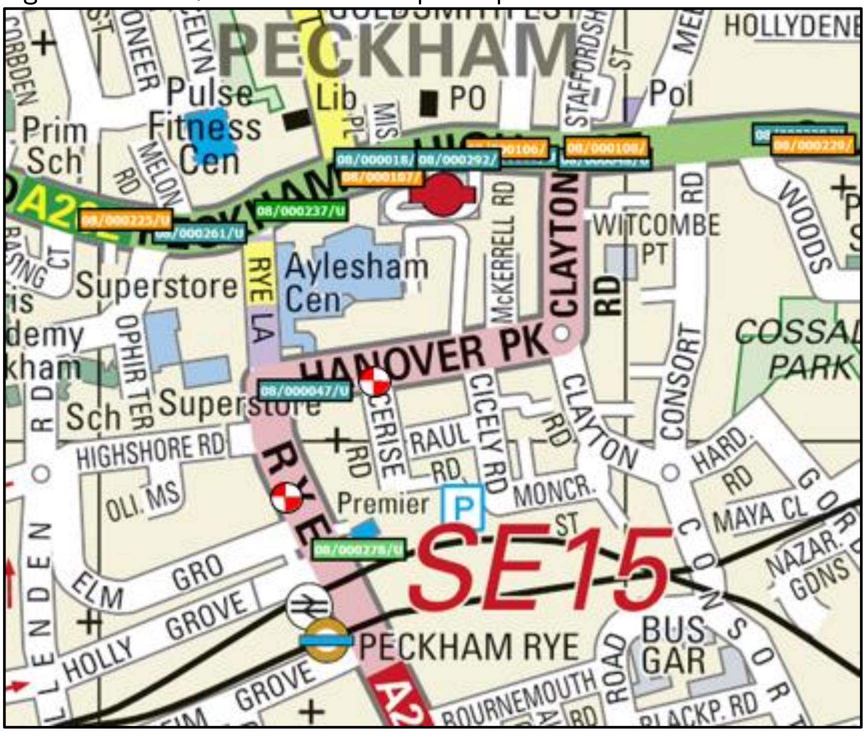
1. A SBn bit with no PR bits indicates a bus within one minute of schedule or early
2. A SBn bit with a PR0 bit indicates a bus 1-3 minutes behind schedule
3. A SBn bit with a PR1 bit indicates a bus 3-5 minutes behind schedule
4. A SBn bit with both PR0 and PR1 bits indicates a bus over 5 minutes behind schedule

Scenario 1 grants no BP, with ever stronger BP being granted from scenarios 2 to 4.

The following example details how a recent study sought to test whether certain routes could be prioritised at a junction operating DBP regardless of lateness by manipulating PR bit returns different to those standard values shown above.

J08/047 (Peckham Rye / Hanover Park) is located in the LB Southwark, just south of the A202 Peckham High Road (TLRN) (see Figure 16). The junction has 14 bus routes, including 5 night bus routes and is already configured to run DBP.

Figure 16 – J08/047 location map and position of VDPs



Different BP thresholds are set which apply depending upon the bus lateness (see Figure 17). Priority level 1, indicating a bus 1-3minutes behind schedule, allows BP extensions, but not recalls. Priority levels 2 and 3 (3-5minutes behind schedule and over 5mins behind schedule respectively) offer both BP extensions and recalls, with higher values set in SCOOT for priority level 3 to offer the best chance of BP occurring.

Figure 17 – Priority levels configured in the SCOOT system.
(Note: The higher the BESAT & BRSAT value the more likely BP will occur. A value of 0% is used to indicate that that particular mode (extension or recall) is not permitted for a bus of that priority level.)

PRLR	BESAT	BRSAT
0	0	0
1	120	0
2	140	120
3	160	140
4	0	0
5	0	0
6	0	0

Buses detected, and what priority level has been assigned, can be analysed in the UTC system. Figure 18 (left table) shows a daily count of buses at J08/047, giving both total count and the priority level count. These figures have been generated according to the standard DBP configuration (detailed above). Note the P3 counts that correspond to buses over 5minutes behind schedule.

But, what if a certain route were deemed more important than other routes at J08/047 – it could be a high patronage route, a high frequency route, an express route or a high revenue route? At J08/047 the BP configuration was modified so that whenever a Route 37 was detected, both PR0 and PR1 are returned, thus designating that bus "behind schedule" (priority level 3) regardless of its actual schedule deviation. Priority 3 BP thresholds then apply and the maximum possible opportunity for BP for that route is given.

The right hand table in Figure 18 show the daily P3 count once this change was made to the BP configuration. It is evident that the hourly totals are higher than the P3 count in the left hand table. This proves the theory that a certain bus could be configured as "high priority" if there was a requirement to do so.

Figure 18 – Priority level counts before (left) and after (right) Route 37 test was configured and undertaken

Hour Ending	Total Count	P0 Count	P1 Count	P2 Count	P3 Count
01:00	55	32	13	4	6
02:00	24	0	0	24	0
03:00	18	0	0	18	0
04:00	15	0	0	15	0
05:00	24	0	0	24	0
06:00	44	0	0	44	0
07:00	75	53	15	6	1
08:00	93	64	19	6	4
09:00	89	57	14	14	4
10:00	85	55	17	3	10
11:00	90	58	18	5	9
12:00	93	50	20	9	14
13:00	89	55	22	7	5
14:00	88	59	15	10	4
15:00	89	52	14	15	8
16:00	86	55	9	11	11
17:00	84	45	15	8	16

Hour Ending	Total Count	P0 Count	P1 Count	P2 Count	P3 Count
01:00	50	29	10	1	10
02:00	20	0	0	20	0
03:00	18	0	0	18	0
04:00	17	0	0	17	0
05:00	23	0	0	23	0
06:00	46	0	0	46	0
07:00	72	43	8	9	12
08:00	87	55	16	4	12
09:00	86	49	10	10	17
10:00	83	45	7	7	24
11:00	91	55	14	7	15
12:00	93	58	16	5	14
13:00	92	56	10	11	15
14:00	88	49	14	5	20
15:00	87	47	16	7	17
16:00	85	45	8	10	22
17:00	90	49	10	12	19

This study proved the concept and this methodology has now been employed for a recently launched Express bus route in West London, the X140. At all junctions, the X140 has been configured as "high priority" to offer the maximum BP possible.

A further development of this, is to add a PR2 bit on the UTC bit pattern in the PROM, to give a further level of differentiation, and priority, between routes. With even higher values configured in SCOOT this would offer even greater BP for "high priority" routes if desired. Figure 19 illustrates this. The drawback of this technique is that a new PROM is required which incurs a greater cost than just manipulating the BP configuration as detailed in this study.

Figure 19 – Addition of PR2 bit allows specific Priority Level 4 values to be added in SCOOT. If desired, levels 5 & 6 could be configured also.

PRLR	BESAT	BRSAT	SKSAT	
0	0	0	0	No PR bits return
1	120	0	0	PR0 only
2	140	120	0	PR1 only
3	160	140	0	PR0 and PR1 return
4	199	199	0	PR2 only
5	0	0	0	PR0 and PR2 return
6	0	0	0	PR1 and PR2 return

5. Bus Recovery / SCOOT Override Data

When BP occurs in SCOOT, there is a period of time where SCOOT may be overridden to both assist the bus through the junction (when priority is granted), and as a period of recovery takes place. SCOOT Traffic Handbook Release Note 484 describes Recovery as the process of resynchronisation with the normal SCOOT stage timings after bus priority has finished. Four methods of recovery are available and which method operates is configurable; different methods can be configured for use after extensions and after recalls. The configuration can be on a node basis but normally the same methods would be used throughout the area.

By analysing SCOOT message data, it is possible to ascertain how long a junction spends in Override. As part of a recent study, three specific elements to Override Time were considered;

1 – Junctions with a very low amount of time spent in Override – this could indicate a junction that has very low BP activity or a fault. Could time be spent reviewing this site to increase BP performance, or indicate poorly located BP equipment that could be relocated elsewhere?

2 – Junctions with a large amount of time spent in Override – this could highlight a junction with too much BP activity, or a junction struggling to recover from BP. More time spent in Override is less time spent on SCOOT control, optimising timings for all users. Time spent reviewing system parameters could improve BP performance at this location also.

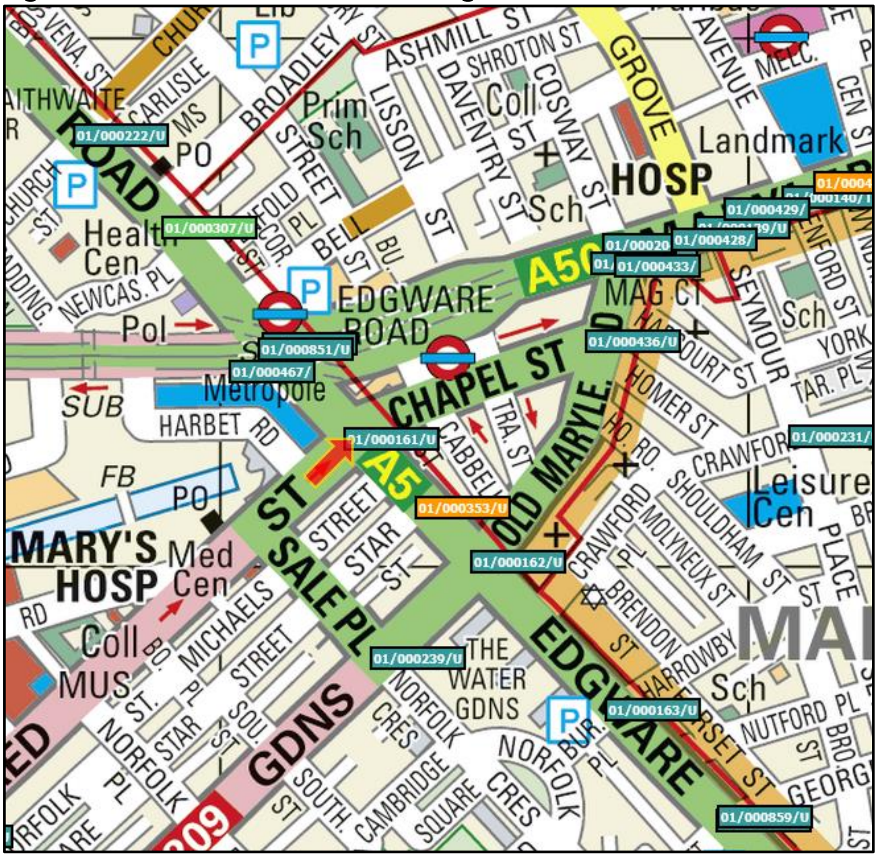
3 – **Junctions which "max out" in Override** – the maximum time spent in Override is 240secs. After this time expires, regardless of the resynchronisation, the junction is handed back to SCOOT. Junctions which frequently "max out" suggest an inability to recover, and warrant review to see if system parameters can be adjusted to improve Recovery. As mentioned above, whilst in Override, SCOOT is not optimising effectively so reviewing these junctions could improve both general and BP performance.

For this study, SCOOT message data for the entire UTC system was acquired over a period of months and the worst offending junctions identified and investigated. Investigations were undertaken to understand why Override time was very low, very high, or reaching maximum value.

Example 1 – Low Recovery Time junction, J01/161 Edgeware Road / Praed Street / Chapel Street)

J01/161 (Figure 20) was identified as a low recovery time junction, with opportunity to increase BP performance. SCOOT message data acquired revealed this junction spent on average only 60 seconds per day in Override.

Figure 20 – Location of J01/161 (Edgeware Road / Praed Street / Chapel Street)



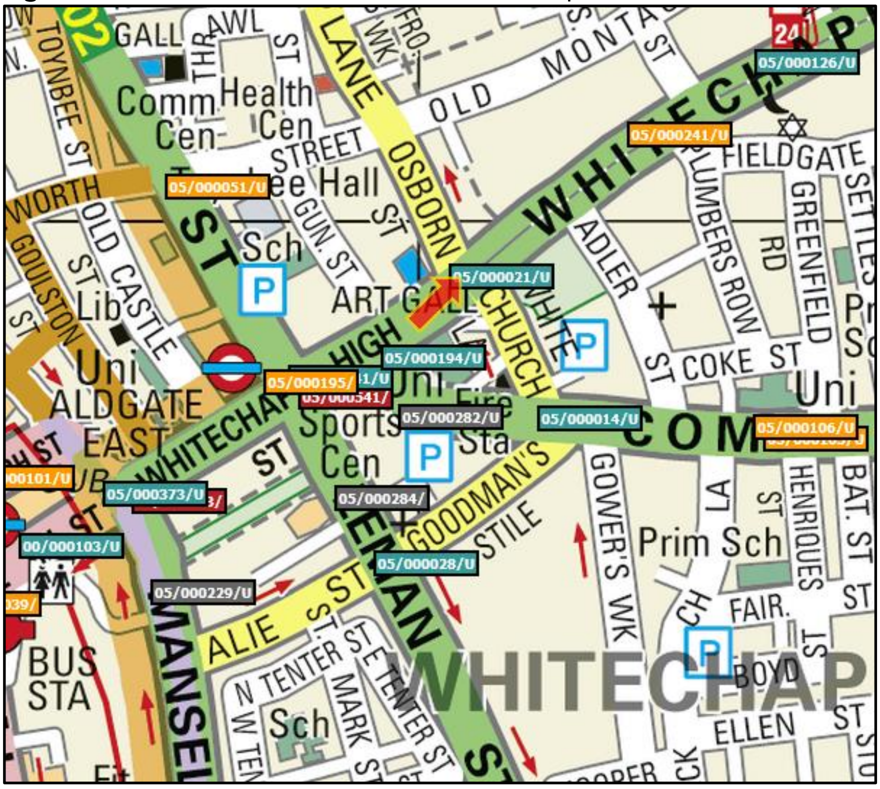
A thorough review of this junction was conducted and numerous system BP parameters updated to enable BP to be more active. Previously only central extensions were permitted on Edgeware Road but, after review, both recalls and extensions were permitted on all approaches. Suitable BESAT & BRSAT values were entered to facilitate this without overly impacting junction operation.

Further SCOOT message data was acquired after system parameter changes were made and the time spent in override increased (from 60 seconds per day) to over 22,000 seconds (366 minutes) per day. This clearly indicates a significant increase in BP activity at this junction.

Example 2 – Low Recovery Time junction, J05/021 (Whitechapel Road / Osbourne Street / Whitechapel High Street)

J05/021 (Figure 21) was also identified as a low recovery time junction, with opportunity to increase BP performance. SCOOT message data acquired revealed this junction spent on average only 656 seconds per day in Override.

Figure 21 – Location of J05/021 – Whitechapel Road / Osbourne Street / Whitechapel High Street



As with J01/161, a review of the junction was undertaken to assess BP system parameters. On this occasion, one of the bus detectors was found to be inhibited meaning that no BP was occurring on one of the approaches to the junction. As part of the review, the bus detector was enabled and updated with appropriate parameters.

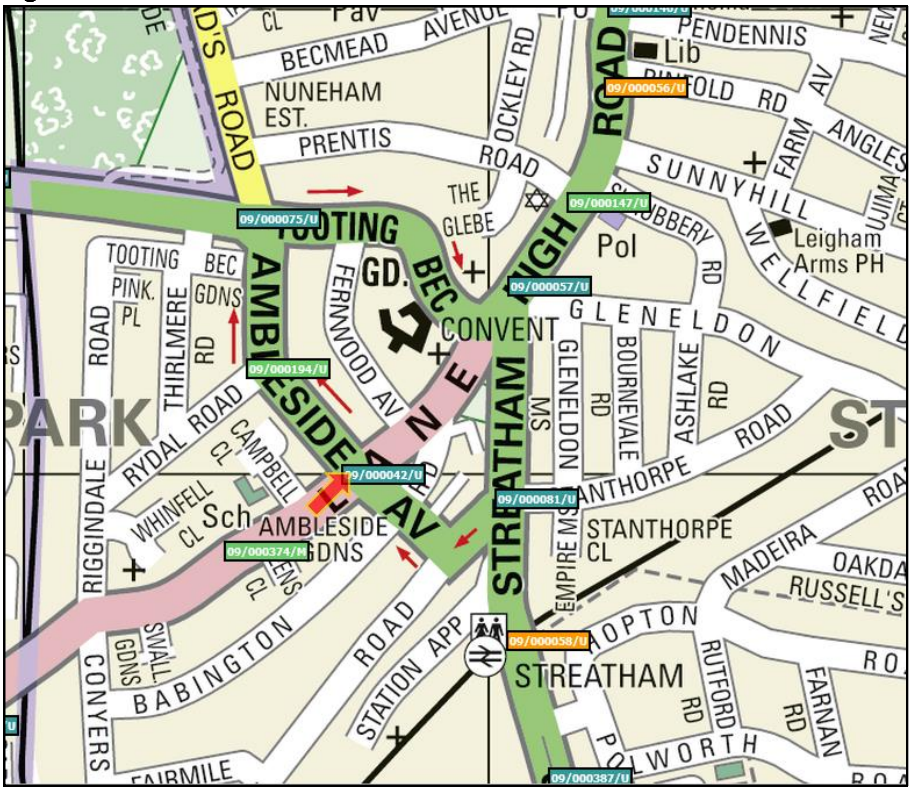
After the changes were made, SCOOT message data was acquired, and the time spent in override increased (from 656 seconds per day) to over 4378 seconds per day. Again, this indicates an increase in BP activity at this junction.

Other reasons for low override times which have been identified include DBP being enabled at all times of day (and not just at suitable time periods) and BP installed at a pedestrian crossing (where only extensions are possible).

Example 3 – "Max out" Override Time junction, J09/042 (Mitcham Lane / Ambleside Avenue)

J09/042 (Figure 22) was identified as a "max out" override time junction. SCOOT message data revealed this junction hit the maximum override timer of 240s between 20 and 25 times times per day. This means it was unable to recover from BP granted and resynchronise with SCOOT, and was therefore dropped off of BP mode and back onto SCOOT in whatever state it was in.

Figure 22 – Location of J09/042 – Mitcham Lane / Ambleside Avenue



An investigation was undertaken and it was found that 7 routes (totalling almost 50 buses per hour) travel through the junction. In addition, BP was configured to allow both extensions and recalls with fairly low thresholds, and various SCOOT stage minimums were applied.

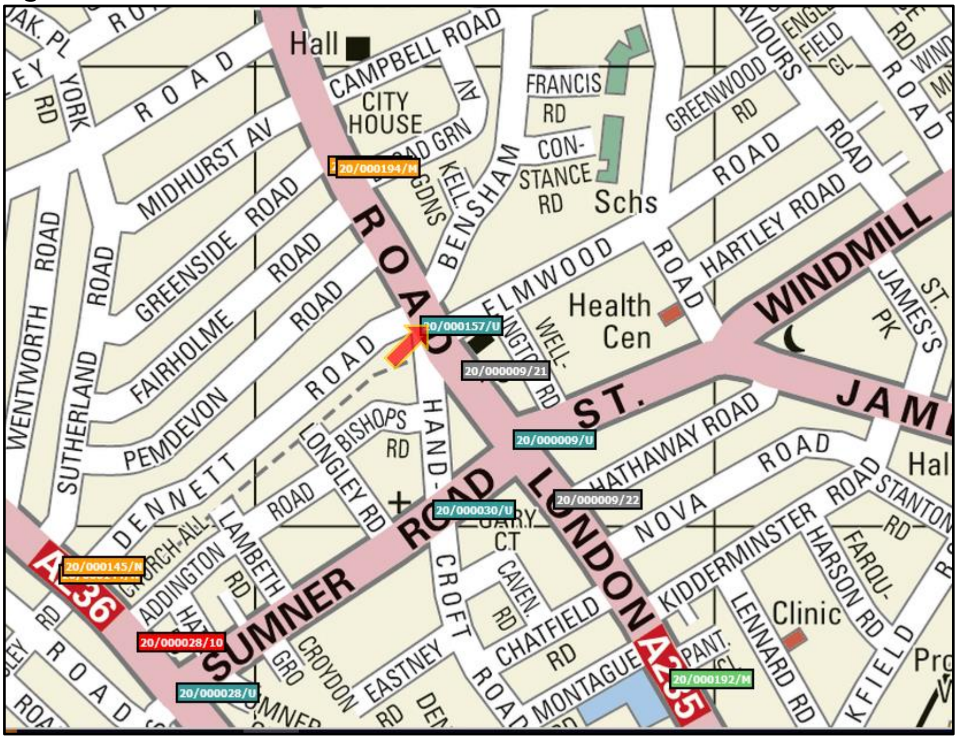
This configuration (with high numbers of buses requesting recalls coupled with minimums on SCOOT stage length) resulted in BP being granted, but then recovery being very restricted for how it could alter junction timings to resynchronise. As a result, resynchronisation could not occur within 240seconds and the max timer was reached.

Options have been identified to resolve this issue, but testing is on hold (at the time of writing) due to changes in traffic patterns resulting from the coronavirus pandemic. These options include adjusting the thresholds for granting BP, removing some of the restrictions on SCOOT stage lengths, and reviewing the recovery method (currently set as "degree of saturation").

Example 4 – High Recovery Time junction, J20/157 (London Road / Sumner Road)

SCOOT message data revealed J20/157 (see Figure 23) to be a high Override time junction – spending 20600 secs per day in Override.

Figure 23 – Location of J20/157 – London Road / Sumner Road



Investigation revealed 8 bus routes travelling through this junction, with up to 80 buses per hour. Both extensions and recalls were configured, with recall thresholds especially being noticeably low given bus numbers and average junction degree of saturation.

It was concluded that the thresholds to allow recalls were set too low, meaning that once a recall was granted, the junction was unable to recover quickly and therefore spent a long time in override. Given that this wasn't identified as a "max out" junction, recovery does occur, but the data suggests it still taking longer than desired.

As with example 3, testing to resolve this high override time is on hold (at the time of writing) due to changes in traffic patterns resulting from the coronavirus pandemic. Adjustments to the BP thresholds or recovery method are two solutions being considered.

In Examples 3 and 4, the type of recovery method configured is briefly mentioned. UTC junctions in London are broadly configured using the "Degree of Saturation (DoS)" recovery method (where target degrees of saturation of used for recovery), but as noted in the introduction to this section, four recovery methods are available. As part of this work, different recovery methods are being investigated to see whether they are more suitable at certain junctions than using DoS.

All four examples given above illustrate how SCOOT message data can identify problems with BP operation at junctions. This data led approach allows us to target staff resource at these locations and further junctions identified by SCOOT Override message data are being reviewed this financial year to maximise the use of BP equipment.

Conclusion

This paper has outlined a number of innovative techniques that have allowed us to maximise the usefulness of our BP equipment and increase our BP capability. In the examples shown, we have significantly increased the number of opportunities for buses to get through the network with lower delay, and often at extremely low cost. TfL's network managers have been trained on how to implement these techniques, and we provide a constant source of support to them. Our hope is that this sharing of knowledge leads not only to more BP on the network, but also further innovation.

These techniques also open up brand new opportunities for us in the future, such as prioritising express or high patronage bus routes. We are constantly trying to improve our knowledge of the system, and will continue to look for new ways to getting the most out of what we already have.

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Traffic Signal Symposium 2020

Session Two

Paper ITS asset management within IMTRAC and developing business cases: the art of getting more money.

By Peter Routledge - IRC. Peter Simpson- Hertfordshire CC, Chris Gladwyn - Ringway

ITS Lifecycle Modelling & Planning: Hertfordshire

Authors:

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- Chris Gladwyn, Ringway
- Peter Routledge, Ian Routledge Consultancy

1. Introduction

Hertfordshire is located in the east of England, just north of London. It has a population of over one million people (the second most densely populated county in the country) and a very busy highway network. Growth over the next 10 to 15 years will see around 175,00 more people and 100,000 more houses. Hertfordshire County Council is the local highway, transport and street lighting authority with a budget for 20-21 of circa £860 million.

We are responsible for managing and maintaining around 5,300km of footways & cycleways, 5,100km of roads, 110,000 street lights and 681 traffic signals (208 no. Junctions, 473 no. Crossings).

We are one of only a few local highway authorities to have an Integrated Transport Control Centre to help us keep Hertfordshire moving and manage our intelligent transport systems, including traffic signals.

This paper sets out how the IMTRAC Asset Lifecycle Planning Module has been used in great effect in Hertfordshire.

Hertfordshire Map

2. IMTRAC LIFE CYCLE PLANNING SCENARIOS

IMTRAC is a comprehensive asset and fault management system that is used in over 80 Local Authorities in the UK and Ireland. Initially deployed in 2008 IMTRAC has evolved in response to user needs/feedback. During 2019 and 2020 the system was further enhanced to allow the asset data within to be used to generate life cycle planning scenarios and support Local Authorities in life cycle planning.

Core Parameters

In order to undertake life cycle planning functions, four core attributes per component are required:

a) Condition. In IMTRAC this is represented as an integer value between 1 (lowest) and 100 (best). Typically, these are allocated as:
   - 100 – Excellent;
   - 75 – Good;
   - 50 – Average;
   - 25 – Poor; and
   - 1 – Failing

b) Age;

c) Replacement cost. The supply and install cost to replace this component, this value is 'rounded' by the user to allow for case by case variances; and

d) Target lifespan. How long the component is expected to 'survive' for, for example a steel pole may be 15 years whereas an aluminium pole may be 50 years.

The core parameters used in the life cycle planning process as follows (Figure 3.1 shows how assets are defined in IMTRAC):

a) Condition and Target Lifespan. The process for degrading asset involves calculating the rate at which a component will degrade, this is known as the component degradation factor. This is calculated by dividing the maximum asset condition (100) by the target life span. Thus, a component with a 15 year life expectancy will degrade by 6.67 points of condition per year;

b) Age. For each year iteration, the component ages by 1 year unless the site is refurbished at which point the age is reinitialised to 0; and

c) Replacement cost. Used to calculate the cost to replace a site (civils and TM costs can also be included).

Figure 3.1 – Equipment at Site

Configuration Options
In order to produce life cycle planning data, the user must first configure the ‘rules’ which the tool will use to generate the output. These are broken down into:

a) Core – high level settings as shown in Figure 3.2. Elements in this section include:
   - Upper year: Range calculations will be performed over
   - Objective (this links to policy objectives):
     - Maintenance spending on condition – spend the defined available money refurbishing the sites in the worst condition first;
     - Maintenance spending on age – spend the defined available money refurbishing the oldest sites first;
     - Maintenance spending to maintain a specified condition – sites are kept at no worse than a specified value regardless of cost. This process can be used to provide a baseline of what ‘acceptable’ estate may cost; and
   - Generation Type:
     - Simple – a single set of values for ‘Maintenance Budget’, ‘Inflation’ and ‘Cost Multiplier’ are utilised; and
     - Complex – yearly values for ‘Maintenance Budget’, ‘Inflation’ and ‘Cost Multiplier’ are utilised. This can be used to model the impact of ‘capital drops’ e.g. significant extra funding in year 8;
   - Maintenance Budget: The amount available for refurbishment in a given year;
   - Inflation: Cost increase per year applied to each component;
   - Maintenance budget inflation: whether inflation is applied to maintenance budget (or not);
   - Cost multiplier: Any costs attributed to a site are multiplied by this value when a refurbishment occurs;
   - Rollover budget: Whether any residual money is carried to the next year; and
   - Minimum condition at which equipment refurbished: Prevents sites being refurbished if there is available money but the site condition is greater than this value.

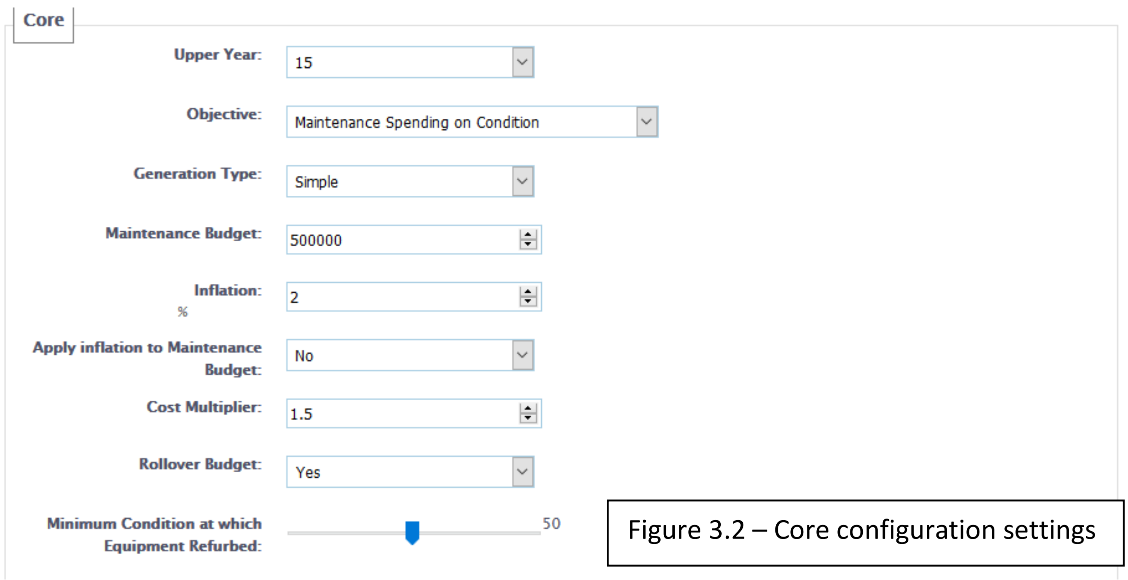


Figure 3.2 – Core configuration settings

b) Asset ‘decisions’ – specific parameters relating to degradation and cost calculations as shown in Figure 3.3:
   - Random degradation factor. This factor allows the component degradation factor to be varied by a random factor between the specified Lower and Upper values (the factor is generated every time the degradation calculator occurs). Thus, in a given year a component can then degrade more ‘randomly’. Using the upper and lower values in Figure 3.2, a component with a 15 year life expectancy may degrade by between 5 and 8.3 points of condition; and

- Set NAL socket quantity = pole quantity. If a pole is not in a NAL socket then one will be added during any refurbishment event;

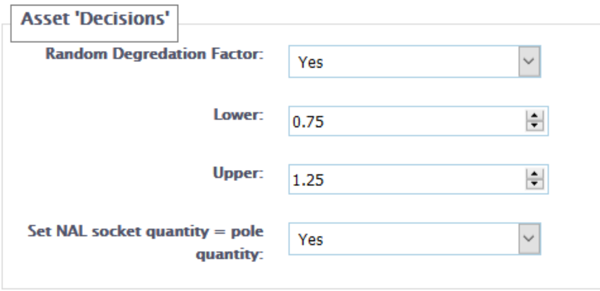


Figure 3.3 – Asset Decisions

c) Site costs – high level costs such as design, traffic management and civil engineering works;

d) Growth – specific parameters relating to how sites will be added to the calculations over the requested period as shown in Figure 3.4:
   - Users can define their own growth values (split by type);
   - On a year by year basis for each equipment type a random value between 0 and the specified ceiling is selected; and
   - The system then clones the returned number of sites at random from the existing sites and reinitialises condition and age values for the cloned site(s);

Figure 3.3 – Growth Settings

e) Output formatting allows users to apply a degree of formatting to the charts and tables that are generated as shown in Figure 3.5:
   - Threshold fields allow users to allocate the 'condition cut points' at which a site is allocated to a colour coded condition bin;
   - Label fields provide the ability for the descriptions within the charts to be as specified by the user;
   - Colour code cells as graph ensures that the colour code utilised in the condition by year graph are also applied to the site by site condition by year table; and
   - Add condition thresholds to average change chart allows two additional fields (per site per year)) to be added to the associated output table;

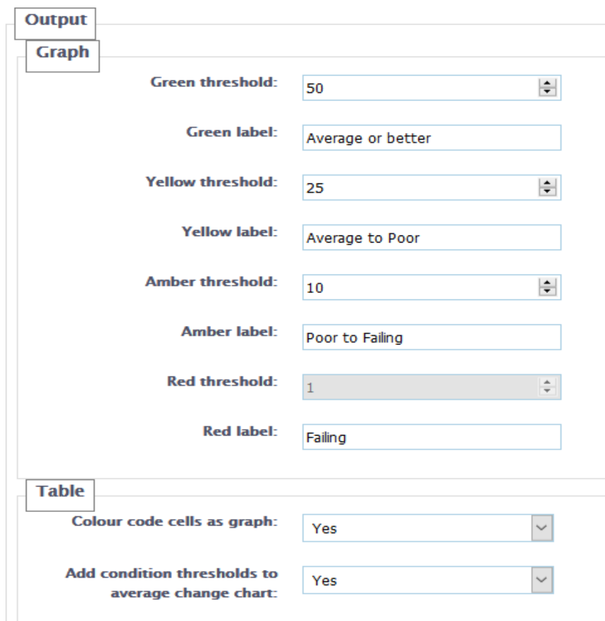


Figure 3.5 – Output Settings

Output

In order to generate the output, the process uses the defined parameters and range specified to create various graphs and tables:

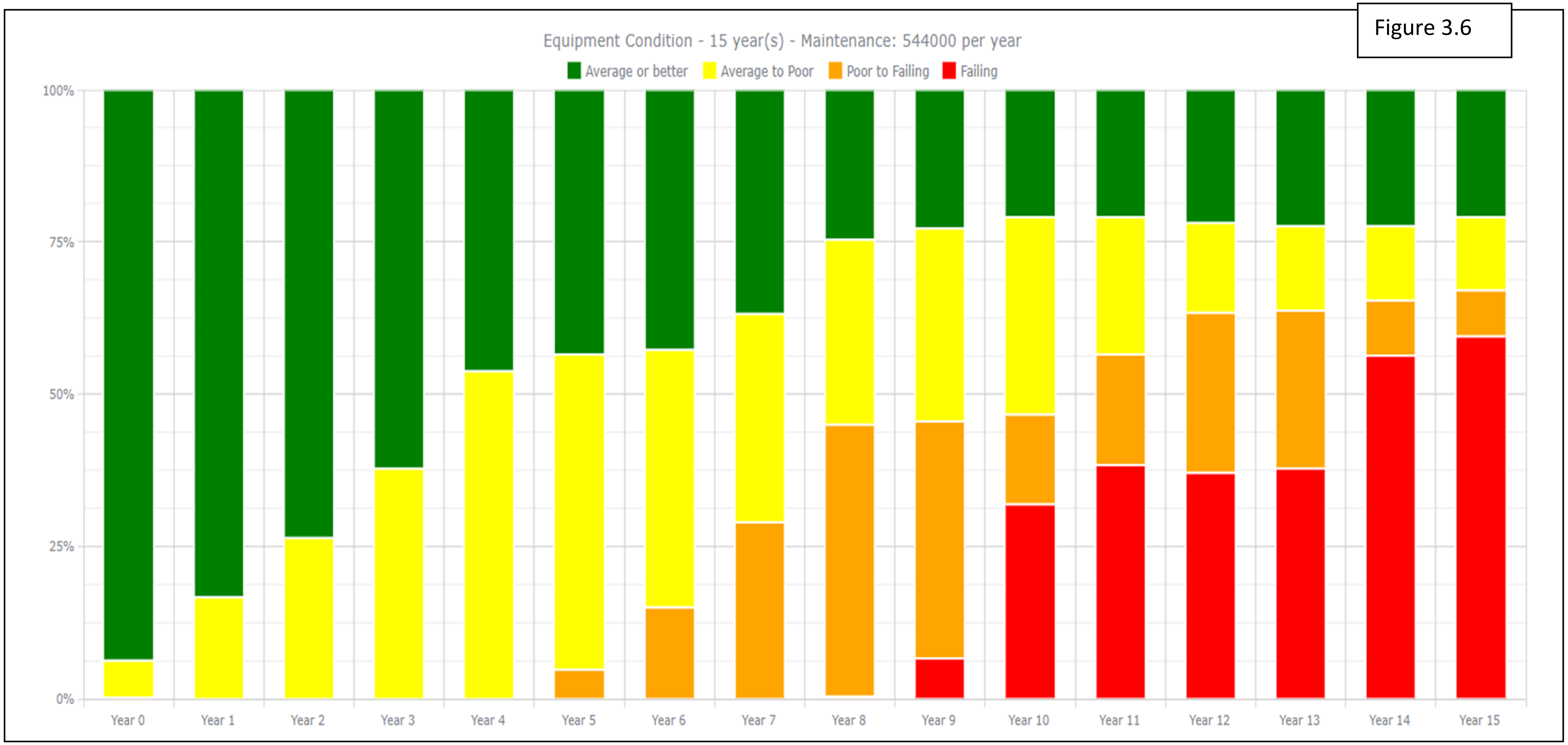
a) Site average condition per year grouped into colour coded condition bins as shown in Figures 3.6 and 3.10. The figures show:
   - Figure 3.6 clearly shows that the proposed refurbishment spend is insufficient to maintain the current estate condition. It is based on:
     - £544k per year refurbishment budget on average asset condition over 15 years;
     - Condition colour coding as follows:
       - Average condition >= 50% = Green;
       - Average condition >=25% but < 50% = Yellow;
       - Average condition >=10% but < 25% = Amber; and
       - Average condition >=0% but < 10% = Red;
     - In year 15 sites are allocated to 'bins' as follows:
       - Green: 156;
       - Yellow: 88;
       - Amber: 56;
       - Red: 441;
   - Figure 3.10 demonstrates that increasing the proposed refurbishment spend is almost sufficient to maintain the current estate condition. It is based on:
     - £1.5m per year refurbishment budget on average asset condition over 15 years;
     - Condition colour coding as follows:
       - Average condition >= 50% = Green;
       - Average condition >=25% but < 50% = Yellow;
       - Average condition >=10% but < 25% = Amber; and
       - Average condition >=0% but < 10% = Red;
     - In year 15 sites are allocated to 'bins' as follows
       - Green: 377;
       - Yellow: 224;
       - Amber: 105; and
       - Red: 38;

b) Number of sites and average condition over time as shown in figures 3.7 and 3.11 show the average site degrades over the specified time period. This data is then in turn used to populate the graphs shown in figures 3.8 and 3.12;

c) Individual site attributes are shown in figures 3.9 and 3.13 which show:
   - The condition of each site (starting in year 0 and modelled thereafter);
   - The expected condition based on the average age of the components at the site relative to the average target expectancy;
   - The average component age relative to the average target life expectancy for the components at the site (negative numbers indicate that the site has exceeded the target); and
   - The estimated cost to replace the site in the given year;

d) Once a number of scenarios have been run it is possible to compare them as shown in figure 3.14

Figure 3.6



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Score	48669	45525	42447	39412	36725	34008	31211	28075	25912	23624	20838	18487	17731	17148	15938	14240
Site No.	683	684	685	685	686	688	689	689	690	692	694	696	697	698	699	699
Average	71.26	66.56	61.97	57.54	53.53	49.43	45.3	40.75	37.55	34.14	30.03	26.56	25.44	24.57	22.8	20.37

Figure 3.7 – Number of sites and average condition over time

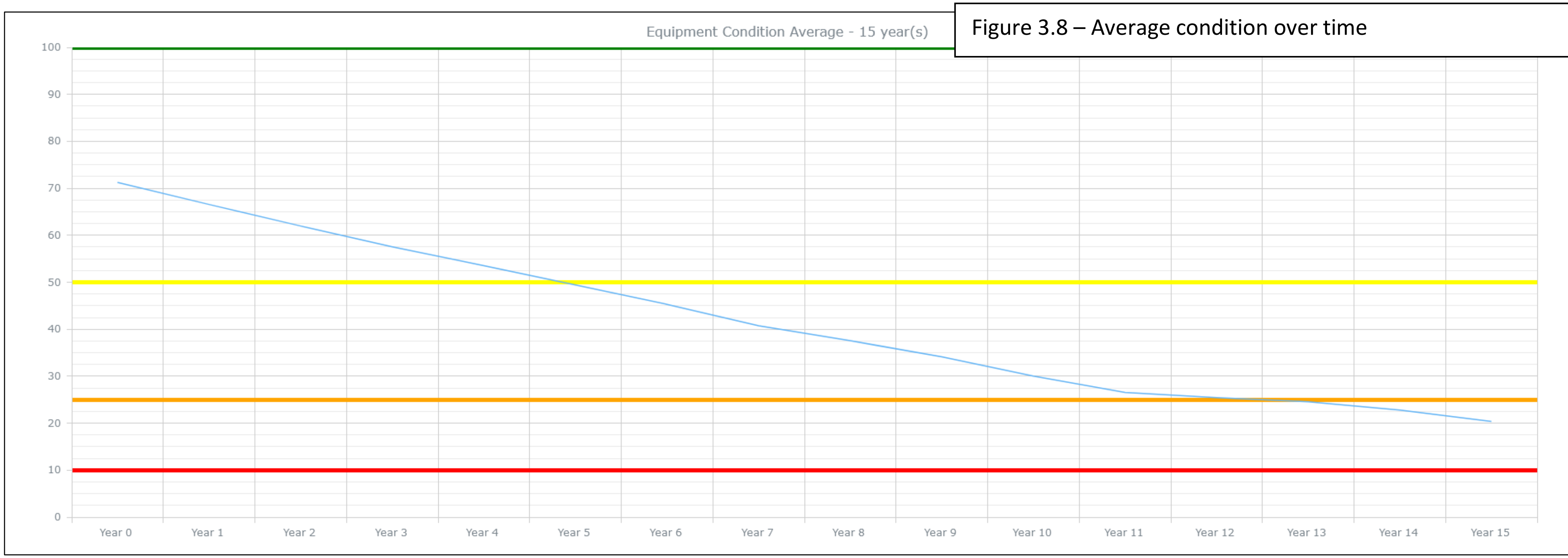


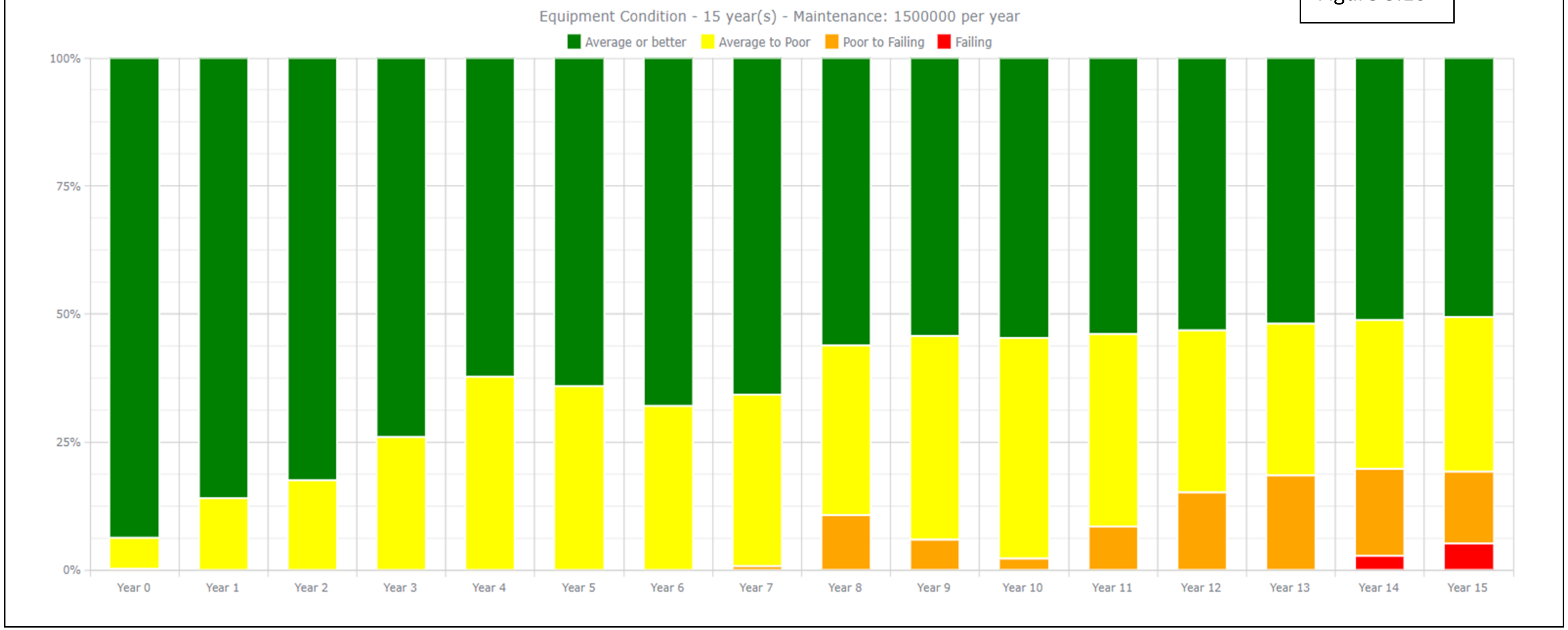
Figure 3.8 – Average condition over time

	0			1				2			
Site ID	Condition	Expected Condition	Age Relative to Target	Condition	Expected Condition	Age Relative to Target	Cost to Replace	Condition	Expected Condition	Age Relative to Target	Cost to Replace
S005	56.84	1	-1.9	50.17	1	-2.9	£38504.01	43.51	1	-3.9	£39142.63
S006	99.22	97.49	14.62	92.55	90.83	13.62	£50280.41	85.88	84.16	12.62	£51286.01
S008	60.32	1	-2.4	53.65	1	-3.4	£25506.09	46.98	1	-4.4	£22340.16
S010	76.4	40	6	69.73	33.34	5	£15321	63.06	26.67	4	£15579.62
S011	63.82	32.55	4.88	57.15	25.88	3.88	£54408.84	50.48	19.22	2.88	£55497.02
S012	70.42	36.95	5.54	63.75	30.29	4.54	£24302.21	57.09	23.62	3.54	£24788.25
S014	60.04	13.59	2.04	53.38	6.93	1.04	£48475.79	46.71	0.26	0.04	£49445.3
S015	62.08	36.39	5.46	55.41	29.72	4.46	£23245.17	48.75	23.05	3.46	£23710.07
S016	54.85	11.22	1.68	48.19	4.55	0.68	£21389.82	41.52	1	-0.32	£21817.62
S017	93.58	94.48	14.17	86.91	87.82	13.17	£15445.82	80.24	81.15	12.17	£15754.73

	3				4				5				6
Site ID	Condition	Expected Condition	Age Relative to Target	Cost to Replace	Condition	Expected Condition	Age Relative to Target	Cost to Replace	Condition	Expected Condition	Age Relative to Target	Cost to Replace	C
S005	36.84	1	-4.9	£42444.74	30.17	1	-5.9	£43109.16	23.51	1	-6.9	£41136.14	
S006	79.22	77.49	11.62	£52311.73	72.55	70.81	10.62	£53357.97	65.88	64.14	9.62	£54425.13	
S008	40.32	1	-5.4	£26343.41	33.68	1	-6.4	£26774.67	27.08	1	-7.4	£29142.35	
S010	56.4	20	3	£14053.18	49.73	13.32	2	£16112.47	43.06	6.65	1	£17350.81	
S011	43.82	12.55	1.88	£56606.96	37.21	5.87	0.88	£57739.1	30.69	1	-0.12	£58893.88	
S012	50.42	16.95	2.54	£25284.01	43.85	10.27	1.54	£25789.69	37.41	3.6	0.54	£26305.49	
S014	40.04	1	-0.96	£50434.21	33.38	1	-1.96	£51442.89	26.71	1	-2.96	£52471.75	
S015	42.08	16.39	2.46	£24184.27	35.62	9.7	1.46	£24667.96	29.47	3.04	0.46	£25161.32	
S016	34.85	1	-1.32	£22253.97	28.69	1	-2.32	£22699.05	23.3	1	-3.32	£23153.03	
S017	73.58	74.48	11.17	£16069.83	66.91	67.8	10.17	£16391.22	60.24	61.13	9.17	£16719.05	

Figure 3.9 – Site by site condition / replacement cost by year

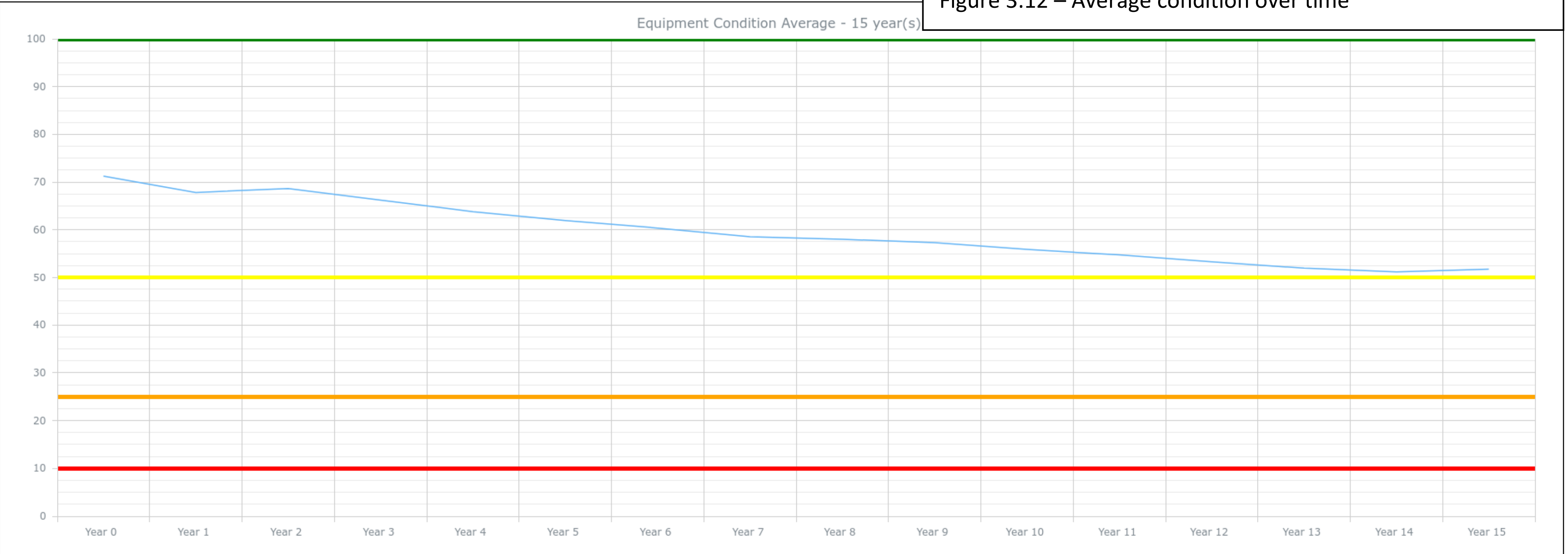
Figure 3.10



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Score	48671	46390	47000	45450	44161	42814	41901	40650	40118	39860	38965	37987	36856	35987	35713	36247
Site No.	683	684	686	688	690	692	694	695	695	697	698	699	699	700	701	702
Average	71.26	67.82	68.51	66.06	64	61.87	60.38	58.49	57.72	57.19	55.82	54.34	52.73	51.41	50.95	51.63

Figure 3.11 – Number of sites and average condition over time

Figure 3.12 – Average condition over time

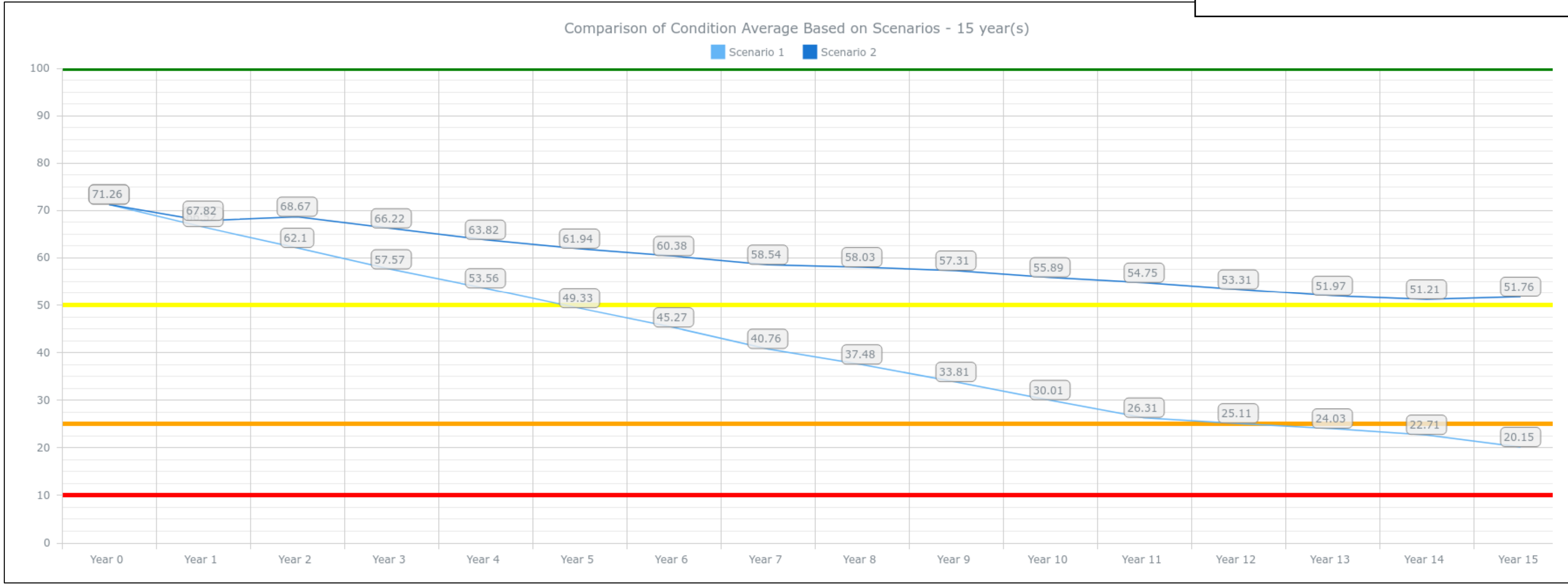


	0			1				2			
Site ID	Condition	Expected Condition	Age Relative to Target	Condition	Expected Condition	Age Relative to Target	Cost to Replace	Condition	Expected Condition	Age Relative to Target	Cost to Replace
S005	56.84	1	-1.9	50.17	1	-2.9	£41154.74	43.51	1	-3.9	£39142.63
S006	99.22	97.49	14.62	92.55	90.83	13.62	£50280.41	85.88	84.16	12.62	£51286.01
S008	60.32	1	-2.4	53.65	1	-3.4	£21925.65	46.98	1	-4.4	£22340.16
S010	76.4	40	6	69.73	33.34	5	£15321	63.06	26.67	4	£15579.62
S011	63.82	32.55	4.88	57.15	25.88	3.88	£54408.84	50.48	19.22	2.88	£55497.02
S012	70.42	36.95	5.54	63.75	30.29	4.54	£24302.21	57.09	23.62	3.54	£24788.25
S014	60.04	13.59	2.04	53.38	6.93	1.04	£48475.79	46.71	0.26	0.04	£49445.3
S015	62.08	36.39	5.46	55.41	29.72	4.46	£23245.17	48.75	23.05	3.46	£23710.07
S016	54.85	11.22	1.68	48.19	4.55	0.68	£21389.82	41.52	1	-0.32	£21817.62
S017	93.58	94.48	14.17	86.91	87.82	13.17	£15445.82	80.24	81.15	12.17	£15754.73

	3				4				5				6			
Site ID	Condition	Expected Condition	Age Relative to Target	Cost to Replace	Condition	Expected Condition	Age Relative to Target	Cost to Replace	Condition	Expected Condition	Age Relative to Target	Cost to Replace	Condition	Expected Condition	Age Relative to Target	Cost to Replace
S005	93.33	100	15	£34870.91	86.67	93.32	14	£34044.51	80	86.65	13	£34725.4	73.33	79.98	12	£35419.91
S006	79.22	77.49	11.62	£52311.73	72.55	70.81	10.62	£53357.97	65.88	64.14	9.62	£54425.13	59.22	57.47	8.62	£55513.63
S008	40.32	1	-5.4	£28271.21	93.33	100	15	£26774.67	86.67	93.33	14	£23080.92	80	86.67	13	£23542.54
S010	56.4	20	3	£16807.3	49.73	13.32	2	£14322.25	43.06	6.65	1	£14596.69	36.4	-0.02	-0	£16666.85
S011	43.82	12.55	1.88	£56606.96	37.21	5.87	0.88	£57739.1	93.33	100	15	£58893.88	86.67	93.33	14	£60237.37
S012	50.42	16.95	2.54	£25284.01	43.85	10.27	1.54	£25789.69	37.41	3.6	0.54	£26305.49	30.98	1	-0.46	£26831.6
S014	40.04	1	-0.96	£50434.21	93.33	100	15	£51442.89	86.67	93.33	14	£53118.56	80	86.67	13	£54180.93
S015	42.08	16.39	2.46	£24184.27	35.62	9.7	1.46	£24667.96	93.33	100	15	£25161.32	86.67	93.33	14	£25830.16
S016	93.33	100	15	£22253.97	86.67	93.32	14	£22858.23	80	86.65	13	£23315.39	73.33	79.98	12	£23781.7
S017	73.58	74.48	11.17	£16069.83	66.91	67.8	10.17	£16391.22	60.24	61.13	9.17	£16719.05	53.58	54.46	8.17	£17053.43

Figure 3.13 – Site by site condition / replacement cost by year

Figure 3.14 – Scenario Comparison



Summary

In summary, the approach is to:

a) Define data required: parameters, treatments, costs, maintenance regimes;
   - Consider strategies: minimising whole life costs, meeting statutory requirements, meeting performance targets, managing risk. Always linked to Asset Management Strategy;
   - Select deterioration profiles: service life, historical performance, local knowledge, best practice;
   - Select scenarios to run: Do Nothing, Do Minimum, Lower than current condition / expenditure, sustaining current condition / expenditure, prioritised improvements / investment, meeting performance targets etc;

b) Use the outputs to gain operational benefits: increased understanding of the network and its performance, data driven inspections and effective use of asset condition, highlighting maintenance regime and delivery;

c) Use the outputs to gain strategic: member / senior officer buy in to support long term investment decisions, support budget decisions and allocations, in this case in 20-21 financial year funding secured for circa 60 sites compared to 23 sites in the financial year 19-20; and

d) Build on the successes achieved to create positive evolution and potential additional applications, e.g. street lighting, safety barriers etc so the benefits achieved for traffic signals can be applied in other areas to support Hertfordshire moving forward ensuring safe, reliable, sustainable and smart travel.

3. What Next

It is acknowledged that thus far the life cycle planning tool within IMTRAC has only begun to scratch the surface of what is possible and the tool will continue to be updated and expanded from user feedback.

Going forward the following developments are planned:

a) Model street lighting data within Hertfordshire;

b) Additional objective to model IMTRAC’s component serviceability index i.e. the measure of obsolescence; and

c) Further granular parameter flexibility.