A ‘Green Wave’ Reprieve

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Executive Summary

Vehicle emissions contribute significantly to global warming and air pollution is harming people’s health. The engineering of cities, particularly traffic signals, can affect the quantity of emissions emitted. It is often assumed within the traffic industry that reducing queuing and journey time is the best way to achieve this. This study puts forward an alternative idea suggesting if emissions are the priority, focusing on reducing the most wasteful stages of driving: stops and starts, should be top of the list. This can be achieved using ‘green waves’. It was found that ‘green waves’ can reduce the waiting time of cars at side roads and pedestrians at crossings. They can intersect multiple other ‘green waves’, will work during the night, are able to be used in both directions. No complex methods or special software/hardware was required.

1. Introduction

In the UK in 2009 27% of total energy consumption was from the burning of oil derivatives for road transport *(DfT 2010)*. In 2008 domestic transport contributed to 21% of all UK greenhouse gas emissions *(DfT 2010)*. Aside from CO_2 other pollutants associated with road transport are Tropospheric Ozone *(Lennard 2010)(Solomon et al. 2007)(Prins et al. 2010)*, oxides of Nitrogen *(Banister 2005)*, Sulphur Dioxide, volatile organic compounds *(J. M. Green 2005)* and Particulate Matter (PM_{10} and $PM_{2.5}$) *(Boulter et al. 2006)(AQEG 2005)*. The UK government has failed to meet EU Air pollution targets that came into effect in 2004 *(Vidal & Mulholland 2010)*. In addition to these, non exhaust emissions e.g. from tyre and brake dust, are also serious pollutants *(Thorpe et al. 2007)(D. I. McCrae 2010)(Sternbeck et al. 2002)(Boulter et al. 2006)*. However there are currently no restrictions for non-exhaust emissions and their effects are poorly understood *(Boulter et al. 2009)*.

Every year air pollutants, largely from road traffic, result in the premature deaths of around 200,000 people in the UK *(COMEAP 2010)*. The government has recognised climate change as the greatest challenge currently facing mankind *(Miliband 2010)(Blair 2007)(Hunt 2010)(Low 2008)(Iddon 2010).*

After investigating the set up of traffic signals around the country it was found that vehicle emissions were rarely considered. When they were it was generally assumed that reducing journey time and congestion would reduce emissions *(Eddy & Rogers 2009)*.

Some calculations were carried out using data from a car on a typical journey around town. This showed that a vehicle travelling along a 2.8 km stretch of road stopping and starting for 5 seconds every 400 metres at traffic signals, would use double the amount of fuel as a vehicle sitting at the start for 2.5 minutes and completing the journey without stopping but in the same time as the first (‘green wave’). In fact had the vehicle sat at the initial signals for 14 minutes it would still have only used the same amount of fuel.

This is because stopping and starting are the most energy intensive and wasteful stages of driving. They also increase wear and tear on all components significantly. A large percentage of the materials in vehicles are metal. Metal mining and manufacture is one of the most energy intensive and polluting industries in the world *(Farrell 2004)*. Reducing the demand for vehicle components could indirectly save significant amounts of energy worldwide.

2. 'Green waves'

Around the world green waves are used to great effect *(C40 Cities 2010)(Naperstek 2007)*. A study in the United States (US) found that optimising signals to the highest recognized standard could save the US 64 billion litres of fuel per year and reduce harmful emissions by 22% *(Peters et al. 2009)*.

In the UK Split Cycle Offset Optimisation Technique (SCOOT) is one of the most common systems for operating signals. It is generally assumed that using SCOOT will reduce delay which in turn will reduce emissions *(Smith et al. 2001)(Phull 2010)*.

Discussions with professionals in the transport industry have uncovered the following attitudes to green waves in the UK:

- Cars at side roads will be left stranded *(Barber 2010)(Baker 2010)*
- 'Green waves' cannot be used on two roads that intersect each other *(Brown 2009)(DoT WA 2003)*
- They are only suited to peak periods *(Diveev et al. 2007)(DoT WA 2003)(Brown 2009)(AA 2009)* and US style grid street layouts *(Phull 2010)*
- Will not work in both directions.
- Only suitable for one way streets *(Bell 1988)*
- Intelligent control systems are required to operate them *(Gaunt 2010)*
- Are only suitable for aiding the progression of emergency vehicles *(DoT 1983)*

3. Aim of study

It is clear road transport has an enormous effect on our environment. Technologies are being developed that may solve some of these problems. However if it is possible that simply altering traffic signal timings can go someway to reducing this impact then this could provide a short term option and should be investigated. This study tested the idea that reducing stops and starts using 'green waves' may help to reduce pollution from traffic and set out to disprove the generally held prejudices against 'green waves'.

With the help of Simon Box at the University of Southampton a model was built relatively quickly in Paramics using ITN map data from EDINA Digital map collections *(EDINA 2010).* Traffic flow and signal plan data was gathered from Manchester UTC and GMTU and an origin/destination matrix estimate was created representing hourly flows for a typical 24 period on a weekday.

4. Status Quo

Currently the main methods of signal operation in the network that was examined are: Fixed time, Vehicle actuation (VA) Adaptive signal control and Split Cycle Offset Optimisation Technique (SCOOT). SCOOT works by analysing different parameters via sensors in the road and inputting them into an online traffic model which derives the optimum signal timings.

Although SCOOT has been proven to reduce congestion compared to fixed time and VA it only works on small areas of the network. Figure 3 shows the areas of the Chorlton network operated under SCOOT highlighted in purple. Figure 5 shows that the use of SCOOT in a much larger area of the Greater Manchester network is very patchy. Each area that is operated under SCOOT is self contained and does not communicate with other areas.

5. Method

Two models were created, the origin/destination matrix and flow profiles were identical, the only differences were the signal plans. One model was designed to replicate the current setup (SCOOT, fixed time and VA) and the other signals were manually setup by observing Paramics and making alterations to reduce stops and starts.

Modelling SCOOT was found to be extremely difficult as was VA, therefore an estimated fixed time setup was used based on signal timing data stored by the ASTRID system. This was not seen as a significant inaccuracy for three reasons:

- Much of the Manchester network is not on SCOOT
- The areas of the network that were are not connected to each other
- The only evidence available that SCOOT is synchronising the traffic signals in each area is the word of signal engineers and SCOOT employees.

It was decided to run the model during the night. The main reasons for this were:

- It was the first time this had been undertaken and basic methods had been used to estimate traffic flows. The rush hour and day time involve much greater volumes of traffic. Any mistakes in the flows will be exaggerated with high traffic volumes.
- The night time is rarely modelled
- It was thought running the model at night would yield the most benefits.

Each model was run 5 times from 10pm to 7am. Using the PHEM emissions analysis module a detailed analysis was produced of the behaviour of each vehicle in the network.

Figure 1 shows an example of the signal setup used on the red ‘green wave’ shown in Figure 4. Table 2 in section 10.1 displays the full signal setup for the ‘green wave’ model and Tables 3,4 and 5 the signal timings for the unsynchronised model.

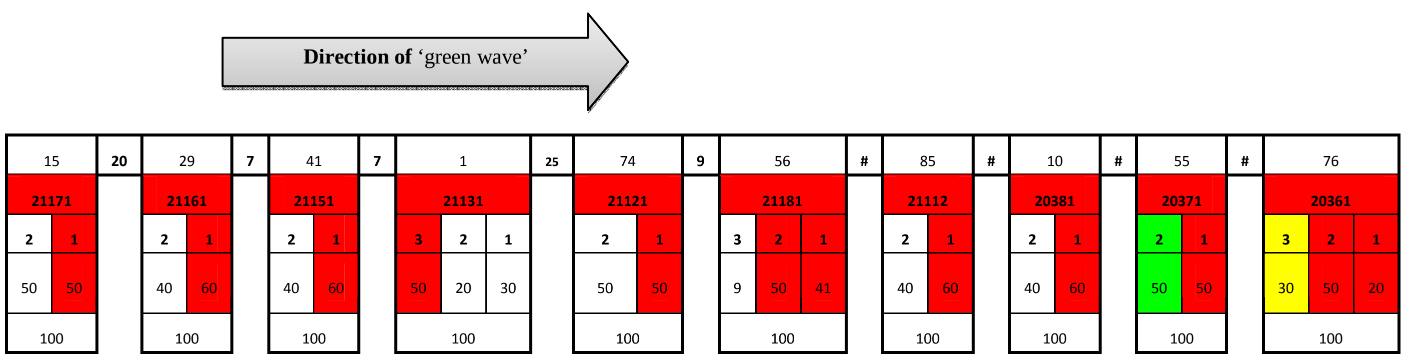

Figure 1 - Example of 'green wave' setup

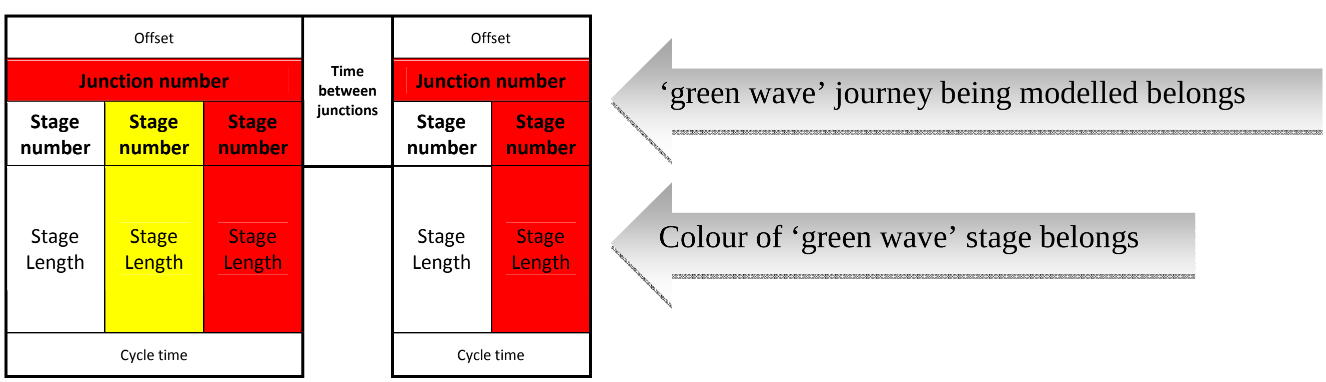

Figure 2 – Key for stage tables

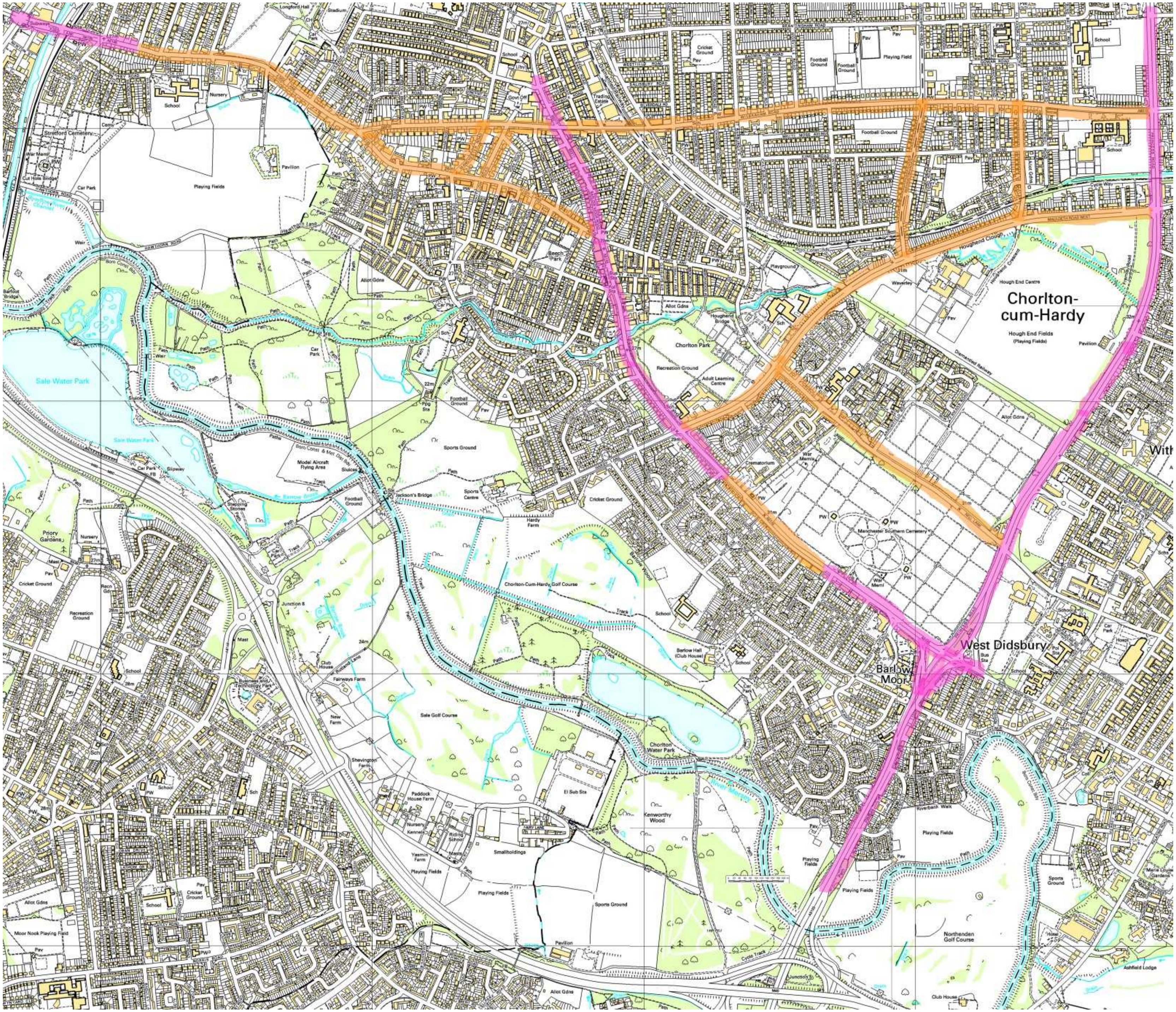

Figure 3 – Road network modelled. Roads operated under SCOOT are marked in purple

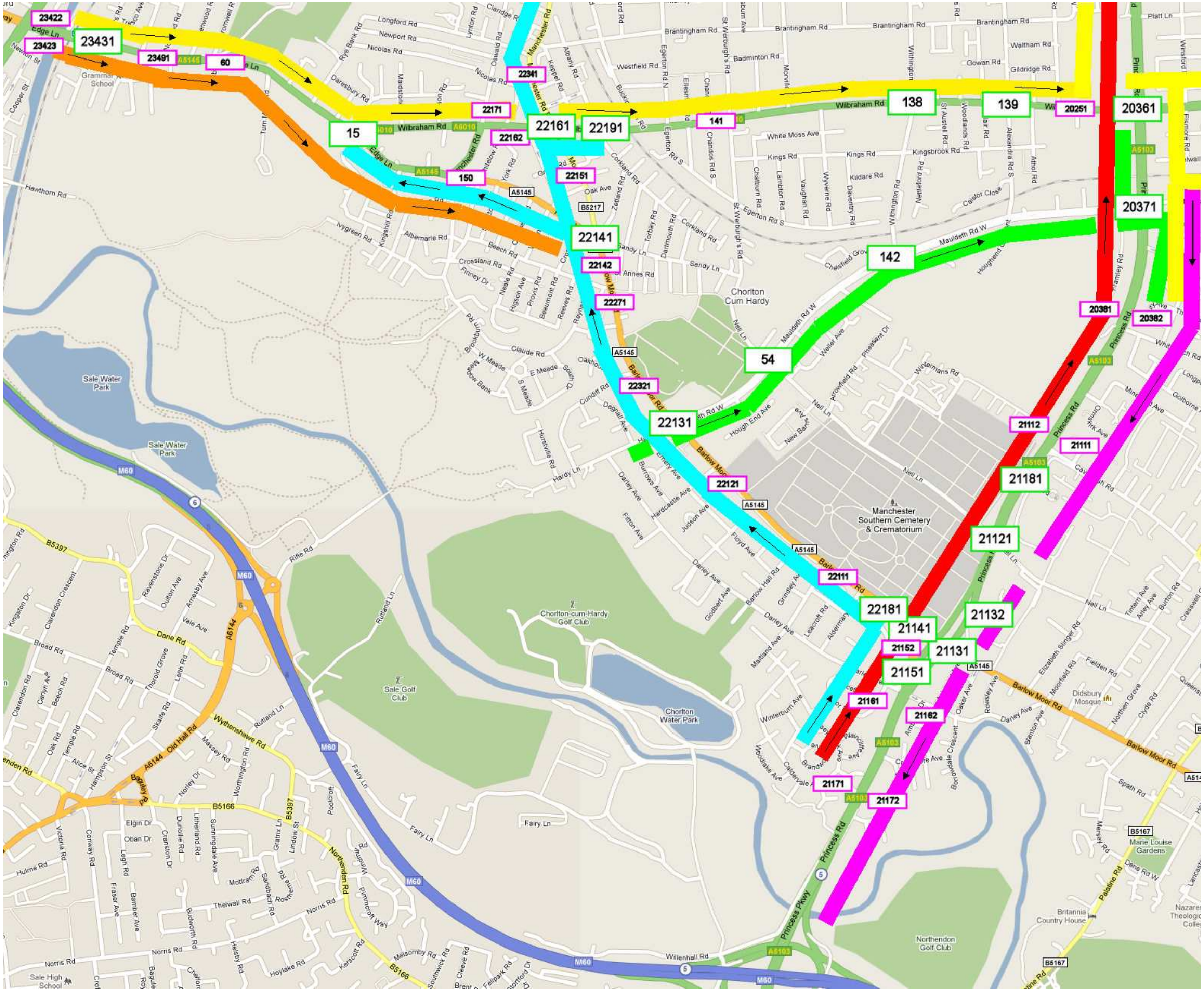

Figure 4 – ‘green wave’ routes colour coded

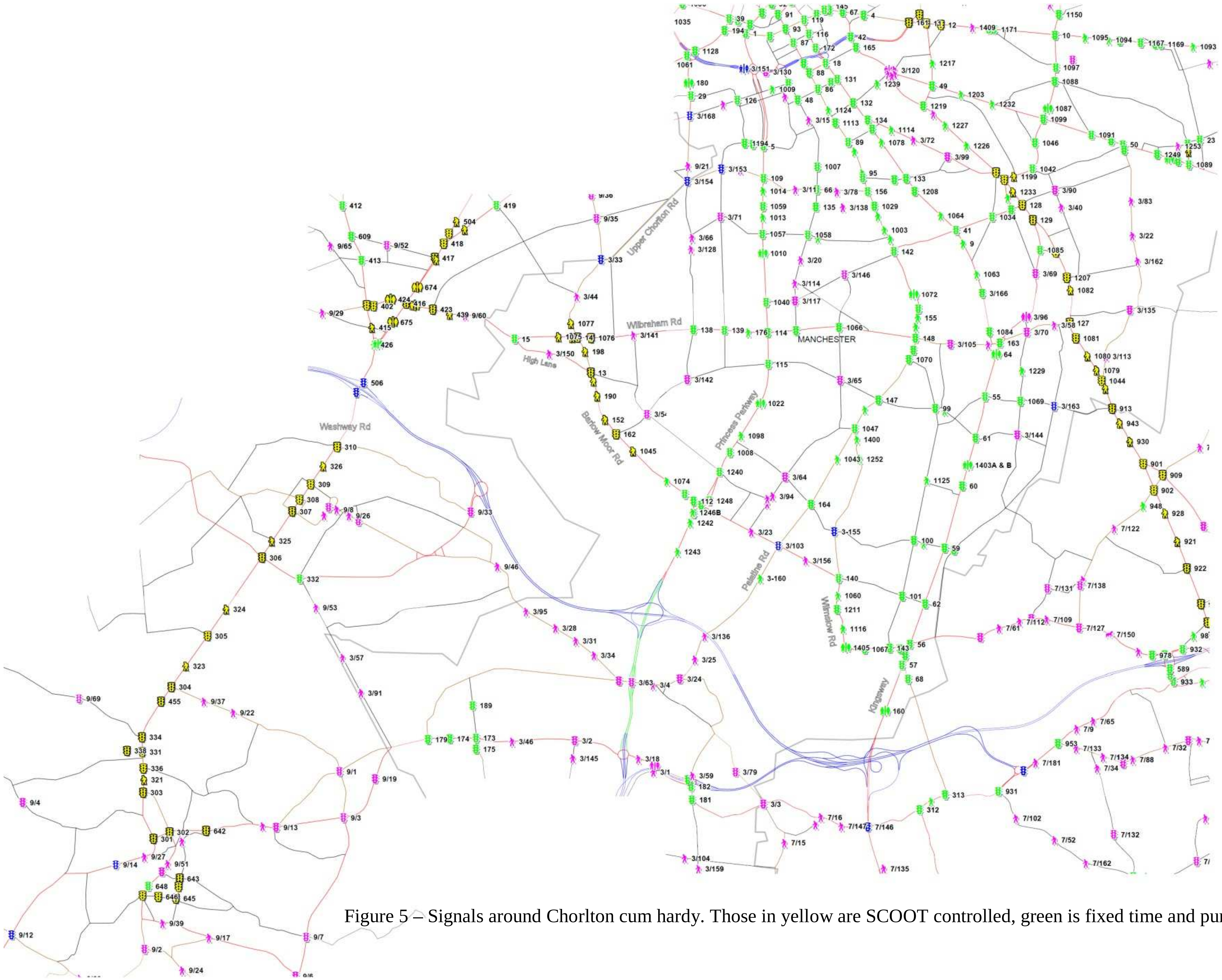

Figure 5 – Signals around Chorlton cum hardy. Those in yellow are SCOOT controlled, green is fixed time and purple VA

6. Results

Table 1 shows the 'green wave' setup in Chorlton ***reduced*** CO_2 emissions by 7.6%, Oxides of Nitrogen (NO_x) by 7.5% and PM_{10} by 4.2%. However the big surprise was that journey time was reduced by 35.2%

Overall Results								
	NO_x (tonnes)	PM_{10} (tonnes)	Carbon Dioxide Equivalent (CO_2(e) tonnes)	Total Network Time (hours)	Total Distance (km)	Vehicles	Average Network Speed (mph)	Average Journey Time (mins)
Unsynchronised	0.04529	0.00120	15.89	2020.5	43956.6	21584	13.52	5.62
'Greenwave'	0.04189	0.00115	14.69	1309.7	43949.7	21461	20.85	3.66

Table 1 - Results

6.1. 'Green waves' in opposite directions

Sections of dual carriageway on the A5103 were also able to be synchronised in the opposite (southerly) direction. This was achieved because the large central reservation provided a safe waiting area for pedestrians enabling the signals on each side of the road to be offset independently of each other. Even though the pedestrian crossing stages are not active at the same time, each one runs for 40 seconds as oppose to between 15 and 20 under SCOOT, it is likely the two will coincide and if not it should only be a short wait.

In the model, the pedestrian stage of pedestrian crossings were set to activate during every cycle, this allowed them to be fully integrated into the synchronisation. In reality however the pedestrian stage would be skipped unless the button is pushed. Depending at what point in the cycle a pedestrian arrives could mean a wait of between 1 and 70 seconds at some crossings. TfL modelling guidelines state waiting time should not exceed 83 seconds *(TfL 2006)* with this system pedestrians crossing with the green man will never affect the synchronised wave of traffic.

6.2. Side roads

It has also been possible to give side roads longer green periods. As an example under SCOOT, Junction 20371 only gave Barlow Moor Road a minimum stage length allocation of 19 seconds and a maximum of 22. The wait until the stage came round again was 75 seconds. Under the ''green wave'' setup it gets 50 seconds with no more than a 50 second wait if a car arrives outside of the synchronised flow.

Overall apart from a few exceptions side roads and pedestrians get more green time as traffic flows are controlled in pulses.

6.3. Intersecting junctions

Signals on opposite sides of the network were co-ordinated. Flows from Zone 1 in the Northwest corner of the model (Junction 23422) arrive just in time to receive the full green period at Junction 20361 5km away on the A5103.

The same is true of traffic along the green colour coded wave beginning at Junction 22131. It is able to flow unhindered through to reach the beginning of its allocated stage at the A5103, junction 20371.

7. Conclusion

The results of this study show that during the night time a ‘green wave’ set up would reduce emissions and fuel consumption when compared with an unsynchronised network.

It was also able to show that cars waiting at side roads to cross the main roads were generally able to have more green light time and less time between stages. The same was also true of pedestrians at crossings.

It was possible to synchronise ‘green waves’ on roads intersecting other roads with green waves.

The stage timing for the ‘green wave’ were the result of manual optimisation and no additional hardware or software, other than Paramics, was required.

The most difficult task in this study was finding accurate data to construct the model with. Traffic modelling software has made big strides over recent years but data gathering is still heavily reliant on long winded techniques and complex statistical analysis. As a result few models are created for large areas due to the costs and difficultly of filling them with data.

It was not possible to find out how SCOOT synchronises traffic systems. However even if it was setting up perfectly optimised green waves, they would only be over a relatively small area.

Because of this traffic is modelled over small areas with the emphasis on queue reduction and the ‘bigger picture’ is largely ignored.

8. Improvements to study

8.1. Data

The biggest improvement to this study would be to have accurate origin/destination data. ANPR cameras or Bluetooth traffic monitoring could provide this information if they were setup around the network.

8.2. SCOOTLINK

In order to accurately measure the improvement over the current network the SCOOTLINK add on for Paramics could be used to accurately model SCOOTs performance.

8.3. Stops and starts

Data on Stops and starts is not an explicit feature of Paramics; however the data necessary to derive the figures can be exported.

8.4. Optimise model based on emissions

Many modelling packages allow optimisation of models based on journey time and other parameters. If an accurate emissions model such as PHEM could be used to perform automatic optimisation based on emissions this could find an improved setup to the one undertaken in this study.

9. References

AA, 2009. Motorists set for “green wave” - statement by spokesperson by the Automobile Association (AA), Published in the Daily Telegraph, 09/04/2009.

AQEG, 2005. *Particulate matter in the United Kingdom*, London: Air Quality Expert Group (AQEG).

Baker, N., 2010. Letter from Norman Baker M.P. Under-Secretary of State for Transport, in response to Councillor Paul Ankers query. 22/06/2010

Banister, D., 2005. *Unsustainable transport - city transport in the new century*, Abingdon, Oxfordshire.

Barber, C., 2010. Email from Chris Barber, head of Highway Services, Highways Agency, Manchester, Subject: Traffic Flow. 15/02/2010

Bell, M.G.H., 1988. *An investigation of the differences between British and German traffic control policies*, University of Nottingham Transport Research Group.

Blair, A., 2007. *Statement on the european summit which took place on the 8/9th March 2007*, Houses of Parliament.

Boulter, P.G. et al., 2009. *Emission factors 2009: Report 1 - a review of methods for determining hot exhaust emission factors for road vehicles.*, Berkshire: Transport Research laboratory (TRL).

Boulter, P.G. et al., 2006. *A review of Abatement measures for non-exhaust particulate matter from road vehicles*, Berkshire: Transport Research Laboratory (TRL).

Brown, D., 2009. Smoothing Traffic Flow - Presentation to the Surface Transport Panel, 24/02/2009.

C40 Cities, 2010. C40 Cities - Climate Leadership Group - Best practices - Transportation - Portland: Traffic signals. Available at: http://www.c40cities.org/bestpractices/transport/portland_traffic.jsp [Accessed August 2, 2010].

COMEAP, 2010. *The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom - A report by the Committee on the Medical Effects of Air Pollutants*, UK: Committee on the Medical Effects of Air Pollutants (COMEAP).

DfT, 2010. Transport Statistics great Britain: 2010, Department for Transport (DfT), 25/11/2010

Diveev, A.I., Severtsev, A. & Kesel’man, Y.K., 2007. The Histogram method for the problem of stochastically optimal city traffic management. *Journal of Machinery Manufacture and reliability*, 36(3).

DoT, 1983. Urban Traffic Control Functional Specification, Department of Transport (DoT), July 1983.

Eddy, R. & Rogers, J., 2009. *Minutes of the meeting of Bristol City Council 28-04-2009*, Bristol: Bristol City Council.

EDINA, 2010. Digimap Collections. Available at: http://edina.ac.uk/digimap/ [Accessed April 8, 2010].

Farrell, L., 2004. *Dirty metals: mining, communities, and the environment*, Earthworks.

Gaunt, G., 2010. Telephone conversation on 03/08/2010 with Gavin Gaunt, Head of Project Modelling and Appraisal, Department for Transport, Subject: Assessing the origins of DfT statement on Greenwaves widely published in the media on 09/04/2009.

Green, J.M., 2005. Impact of reduced emissions on air quality - The monitoring of aromatics and aldehydes - 1995 - 2003.

Hunt, L., 2010. *Second reading of the 2010 energy bill*, House of Lords.

Iddon, B., 2010. *Westminister debates - UK Chemical Industry*,

Lennard, H., 2010. 'Rethinking climate change' interview with Mike Hulme. *Costing the Earth*, BBC Radio 4.

Low, L., 2008. *Queens speech - debate (3rd Day), 08/12/2008, Houses of Parliament*,

McCrae, D.I., 2010. *Environmental Audit Committee - Air Quality*, 16/03/2010, London: House of commons.

Miliband, E., 2010. *Copenhagen Climate Change Conference, Oral answers to questions, 05/01/2010, Houses of Parliament*,

Naperstek, A., 2007. Streetsblog New York City□» Traffic Signals Timed for Bicycling. Available at: http://www.streetsblog.org/2007/01/17/traffic-signals-timed-for-bicycling/ [Accessed August 2, 2010].

Peters, J., McCourt, R. & Hurtado, R., 2009. Reducing Carbon Emissions and congestion by co-ordinating traffic signals. *Institute of Transport Engineers Journal*.

Phull, S., 2010. Email from Suku Phull, Department for Transport, 27/09/2010, Subject: RE: Fuel Duty.

Prins, G. et al., 2010. The Hartwell Paper: a new direction for climate policy after the crash of 2009.

Smith, K., Wood, K. & Ash, A., 2001. Managing emissions from vehicles in urban areas. *Association for European Transport*.

Solomon, S. et al., 2007. *Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change*, Cambridge: IPCC.

Sternbeck, J., Sj\ödin, A. \AA & Andréasson, K., 2002. Metal emissions from road traffic and the influence of resuspension–results from two tunnel studies. *Atmospheric Environment*, 36(30), pp.4735–4744.

TfL, 2006. DTO Modelling guidelines Version 2, Transport for London (TfL), July 2006.

Thorpe, A.J. et al., 2007. Estimation of particle re-suspension source strength on a major London Road. *Atmospheric environment*, 41(37), pp.8007–8020.

Vidal, J. & Mulholland, H., 2010. UK given final warning over London air quality | Environment | The Guardian. *The Guardian*. Available at: http://www.guardian.co.uk/environment/2010/jun/03/uk-warning-london-air-quality [Accessed August 14, 2010].

DoT WA, 2003. *Coordination of traffic signals - information for the local impacts committee*, Department of Transport Western Australia.

10. Appendix
10.1. Green Wave

Value	ID	Phases	Splits	Cycle	To next
24	23422	2, 1	70, 30	100	13
37	23431	3, 2, 1	47, 23, 30	100	16
43	23491	2, 1	70, 30	100	13
56	60	2, 1	70, 30	100	46
7	15	5, 4, 3, 2, 1	15, 14, 11, 30, 30	100	36
38	N22171	2, 1	50, 50	100	11
54	N22162	2, 1	50, 50	100	5
24	N22161	1, 2, 3	50, 20, 30	100	36
0	N22191	1, 2, 3	30, 23, 47	100	36
23	141	2, 1	50, 50	100	52
78	138	2, 1	50, 50	100	27
5	139	2, 1	50, 50	100	20
25	N20251	2, 1	50, 50	100	16
76	N20361	3, 2, 1	30, 50, 20	100	

Value	ID	Phases	Splits	Cycle	To next
24	23422	2, 1	70, 30	100	13
37	23431	3, 2, 1	47, 23, 30	100	16
43	23491	2, 1	50, 50	100	13
56	60	2, 1	50, 50	100	46
7	15	5, 4, 3, 2, 1	15, 14, 11, 30, 30	100	32
34	150	2, 1	50, 50	100	41
92	N22141	1, 2, 3, 4	48, 11, 29, 12	100	

Value	ID	Phases	Splits	Cycle	To next
37	21152	2, 1	40, 60	100	2
5	21141	2, 1	50, 50	100	9
61	22181	2, 1	40, 60	100	19
75	22111	2, 1	40, 60	100	39
15	22121	2, 1	40, 60	100	20
4	22131	2, 3, 1	30, 20, 50	100	16
40	22321	2, 1	40, 60	100	22
72	22271	2, 1	40, 60	100	14
86	22142	2, 1	40, 60	100	6
92	22141	1, 2, 3, 4	48, 11, 29, 12	100	20
8	22151	2, 1	50, 50	100	14
24	22161	3, 2, 1	20, 30, 50	100	17
4	22341	2, 1	40, 60	100	

Value	ID	Phases	Splits	Cycle	To next
40	22131	2, 3, 1	30, 20, 50	100	32
92	54	2, 1	50, 50	100	43
35	142	1, 2, 3, 4, 5	50, 6, 25, 13, 6	100	73
55	20371	2, 1	50, 50	100	

Value	ID	Phases	Splits	Cycle	To next
15	21171	2, 1	50, 50	100	20
29	21161	2, 1	40, 60	100	7
41	21151	2, 1	40, 60	100	7
1	21131	3, 2, 1	50, 20, 30	100	25
74	21121	2, 1	50, 50	100	9
56	21181	3, 2, 1	9, 50, 41	100	12
85	21112	2, 1	40, 60	100	25
10	20381	2, 1	40, 60	100	35
55	20371	2, 1	50, 50	100	21
76	20361	3, 2, 1	30, 50, 20	100	

Value	ID	Phases	Splits	Cycle	To next
55	20371	2, 1	50, 50	100	35
80	20382	2, 1	40, 60	100	25
5	21111	2, 1	40, 60	100	12
56	21181	3, 2, 1	9, 50, 41	100	9
Stop 74	21121	2, 1	50, 50	100	20
64	21132	2, 1	40, 60	100	6
Stop 99	21131	3, 2, 1	50, 20, 30	100	14
3	21162	2, 1	40, 60	100	21
24	21172	2, 1	40, 60	100	

Table 2 – Full colour coded 'green wave' setup

10.2. Unsynchronised

	SCOOT Stretford region							Fixed time/VA																					
	0		0			0		0							0		0		0		0							0	
	23422		23431			23491		15					54		60		138		139		141		142					150	
Period	2	1	3	2	1	2	1	5	4	3	2	1	2	1	2	1	2	1	2	1	2	1	1	2	3	4	5	2	1
1	23	41	21	16	33	23	41	27	13	15	25	25	47	32	27	27	12	12	12	12	27	27	47	12	37	14	17	17	77
	64		70			64		105					92		54		24		24		54		127					94	
2	23	40	22	16	31	23	39	27	13	15	25	25	47	32	27	27	12	12	12	12	27	27	47	12	37	14	17	17	77
	63		68			62		105					92		54		24		24		54		127					94	
3	23	39	22	16	30	23	39	27	13	15	25	25	47	32	27	27	12	12	12	12	27	27	47	12	37	14	17	17	77
	63		68			62		105					92		54		24		24		54		127					94	
4	23	39	23	16	29	23	39	27	13	15	25	25	47	32	27	27	12	12	12	12	27	27	47	12	37	14	17	17	77
	62		68			62		105					92		54		24		24		54		127					94	
5	23	39	23	16	29	23	38	27	13	15	25	25	47	32	27	27	12	12	12	12	27	27	47	12	37	14	17	17	77
	62		68			62		105					92		54		24		24		54		127					94	
6	23	40	22	16	31	23	39	27	13	15	25	25	47	32	27	27	12	12	12	12	27	27	47	12	37	14	17	17	77
	63		69			62		105					92		54		24		24		54		127					94	
7	23	47	23	16	38	23	47	27	13	15	25	25	47	32	27	27	12	12	12	12	27	27	47	12	37	14	17	17	77
	70		77			70		105					92		54		24		24		54		127					94	
8	22	45	21	15	39	22	45	27	13	15	25	25	47	32	27	27	30	42	30	42	27	27	47	12	37	14	17	17	77
	68		76			68		105					92		54		72		72		54		127					94	
23	23	47	21	16	39	23	47	27	13	15	25	25	47	32	27	27	12	12	12	12	27	27	47	12	37	14	17	17	77
	70		76			70		105					92		54		24		24		54		127					94	
24	23	43	21	16	35	23	43	27	13	15	25	25	47	32	27	27	12	12	12	12	27	27	47	12	37	14	17	17	77
	66		72			66		105					92		54		24				54		127					94	

Table 3 – Unsynchronised setup

	Chorlton SCOOT region																																		
	0							6				8				2		18													58		36		0	
	N20251		N20361			22121		22131				N22141				22142		22151		N22162		N22161			N22171		N22191			22271		22321		22341	
Period	2	1	3	2	1	2	1	2	3	4	1	1	2	3	4	2	1	2	1	2	1	1	2	3	2	1	1	2	3	2	1	2	1	2	1
1	15	33	39	40	17	21	51	28	9	20	15	21	18	17	16	15	55	15	55	15	58	29	16	28	21	52	40	17	16	15	55	15	55	15	55
	48		96			72		73				73				70		70		73		73			73		73			70		70		70	
2	15	33	40	40	17	21	51	28	9	20	15	21	18	17	16	15	55	15	55	15	58	29	16	28	21	52	40	17	17	15	55	15	55	15	55
	48		96			72		72				72				70		70		73		73			73		73			70		70		70	
3	15	33	39	41	17	21	51	28	9	20	15	21	18	17	16	15	55	15	55	15	58	29	16	28	21	52	39	17	17	15	55	15	55	15	55
	48		96			72		72				72				70		70		73		73			73		73			70		70		70	
4	15	33	34	46	17	21	51	28	9	20	15	21	18	17	16	15	55	15	56	15	58	29	16	28	21	52	40	17	17	15	55	15	55	15	55
	48		96			72		73				72				70		71		73		73			73		73			70		70		70	
5	15	33	31	48	17	21	51	28	9	20	15	21	18	17	16	15	55	15	56	15	58	29	16	28	21	52	40	17	17	15	55	15	55	15	55
	48		96			72		72				72				70		71		73		73			73		73			70		70		70	
6	15	33	27	53	17	21	51	28	9	20	15	21	18	17	16	15	55	15	55	15	58	29	16	28	21	52	40	17	16	15	55	15	55	15	55
	48		96			72		72				72				70		70		73		73			73		73			70		70		70	
7	15	33	25	55	17	21	50	28	10	20	15	22	18	17	16	15	55	15	54	15	59	30	16	29	21	53	41	17	17	15	54	15	54	15	55
	48		96			71		74				74				70		69		74		74			74		74			69		69		70	
8	15	36	25	59	18	21	44	35	14	20	17	31	18	20	17	15	42	15	42	15	71	32	16	39	21	65	53	17	17	15	42	15	42	15	43
	51		102			65		86				86				57		57		86		86			86		86			57		57		58	
23	15	33	37	43	16	21	51	28	9	20	15	22	18	17	16	15	55	15	55	15	58	29	16	28	21	52	40	17	16	15	54	15	55	15	55
	48		97			72		73				73				70		70		73		73			73		73			69		70		70	
24	15	33	36	44	16	21	51	28	9	20	15	22	18	17	16	15	55	15	55	15	58	29	16	28	21	52	40	17	16	15	55	15	55	15	55
	48		96			72		73				73				70		70		73		73			73		73			70		70		70	

Table 4 – Unsynchronised setup

	Princess Parkway SCOOT																																			
			0				21		46				0								27		20				0				9					9	
	20371		21121		21111		21112		20381		20382		21131			21132		21141		21151		21161		21162		21171		21172		21181			22111		22181	
Period	2	1	2	1	2	1	2	1	2	1	2	1	3	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	3	2	1	2	1	2	1
1	21	75	22	75	15	33	15	33	20	28	20	28	62	7	22	14	83	59	32	28	68	15	33	15	33	15	33	15	33	16	25	56	23	25	59	32
	96		97		48		48		48		48		91			97		91		97		48		48		48		48		96			48		91	
2	21	76	22	75	15	33	15	33	20	28	20	28	62	7	22	14	83	60	33	28	68	15	33	15	33	15	33	15	33	16	25	56	23	25	59	32
	96		97		48		48		48		48		91			97		93		97		48		48		48		48		96			48		91	
3	20	76	22	75	15	33	15	33	20	28	20	28	62	7	22	14	83	59	33	28	68	15	33	15	33	15	33	15	33	16	25	56	23	25	59	32
	96		97		48		48		48		48		91			97		92		97		48		48		48		48		97			48		91	
4	19	77	22	75	15	33	15	33	20	28	20	28	62	7	22	14	83	60	33	28	68	15	33	15	33	15	33	15	33	16	25	56	23	25	59	32
	97		97		48		48		48		48		91			97		93		97		48		48		48		48		97			48		91	
5	19	77	21	75	15	33	15	33	20	28	20	28	62	7	22	14	83	60	32	29	68	15	33	15	33	15	33	15	33	16	25	56	23	25	59	32
	96		97		48		48		48		48		91			97		92		96		48		48		48		48		97			48		91	
6	19	77	22	75	15	33	15	33	20	28	20	28	62	7	22	14	83	60	32	29	68	15	33	15	33	15	33	15	33	16	25	56	23	25	59	32
	96		97		48		48		48		48		91			97		92		97		48		48		48		48		96			48		91	
7	20	76	22	74	15	33	15	33	20	28	20	28	62	7	22	14	83	61	31	29	68	15	33	15	33	15	33	15	33	16	25	55	23	25	59	32
	96		96		48		48		48		48		91			97		93		96		48		48		48		48		96			48		91	
8	20	82	23	79	15	36	15	36	20	31	20	31	67	7	23	14	88	65	33	30	73	15	36	15	36	15	36	15	36	16	26	59	23	28	59	32
	102		102		51		51		51		51		97			102		98		102		51		51		51		51		102			51		91	
23	21	76	22	75	15	33	15	33	20	28	20	28	62	7	22	14	83	59	33	29	67	15	33	15	33	15	33	15	33	16	25	56	23	25	59	32
	97		97		48		48		48		48		91			97		92		97		48		48		48		48		96			48		91	
24	21	76	22	75	15	33	15	33	20	28	20	28	61	7	23	14	83	59	33	29	67	15	33	15	33	15	33	15	33	16	25	56	23	25	59	32
	96		97		48		48		48		48		91			97		92		96		48		48		48		48		96			48		91	

Table 5 – Unsynchronised setup