The effect of minor traffic signals faults on congestion and emissions

Nick Warwick is the traffic signals team leader for Cumbria County Council, the following comments are his opinions, rather than a policy of Cumbria County Council.

Introduction

Like many other Local Authorities, Cumbria has its fair share of traffic issues and challenges in 'securing the expeditious movement of traffic'. Several years ago, I realised that I needed to sort out how I was going to deal with the sheer volume of complaints I was having to deal with.

At that time, the Received Wisdom (as I understood it) was that a traffic complaint comes in; we look at the complaint to determine what the issue is; we act on what we find.

Since then, I've entirely changed my approach in dealing with faults – I appreciate the distinction between 'complaints' and 'faults'. In addition, I think I've also been able to make some improvements in reducing vehicle emissions and reducing vehicle delays, which I do hope you'll find interesting and useful.

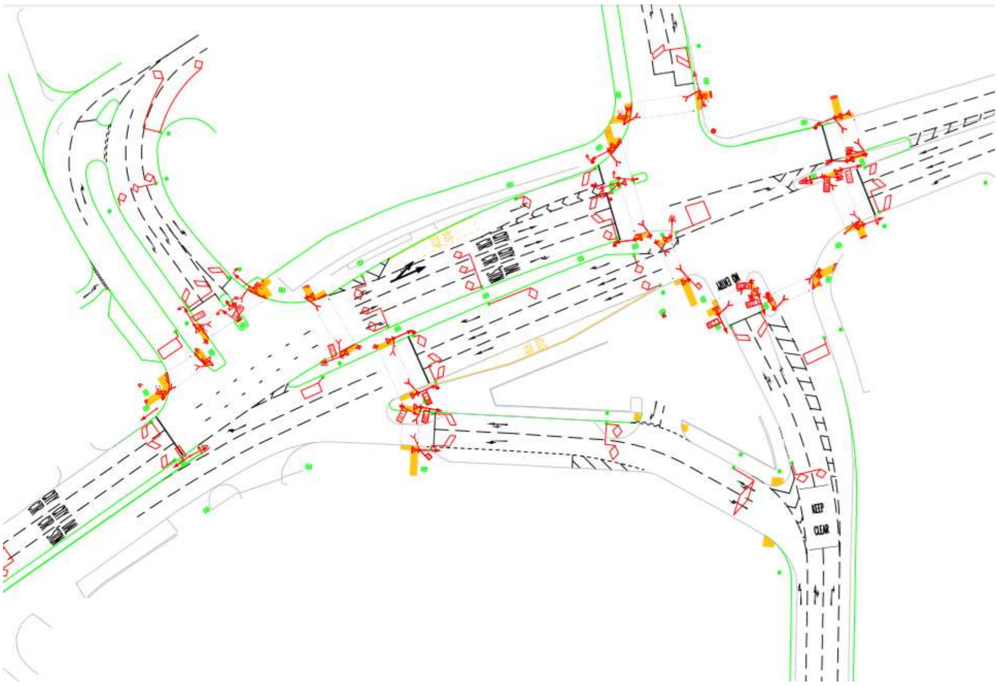
The nature of traffic faults and complaints

Going back to 2012, we received about 360 complaints from the public over a nine-month period. I thought I'd break it down and look at the detail:

- **26% of the faults were specific comments and complaints** – along the lines of 'green man not showing', 'traffic signals are all out', 'red lamp not working'
- **47% of the faults were more general** – for example 'Signals only letting a few cars through at a time causing long tailbacks', 'caller says that just before the bank holiday he thinks that the timings have been altered on the lights on the junction and are just letting 3 cars through at a time'
- **27% were non-traffic signals related** – these were along the lines of zebra crossing issues, school flashing lights, various issues, but not permanent traffic signals

So, what do we see with the nature of the fault? People can and do let you know if there's a fault – however, the only specific thing that they can report is something that they can see, such as a lamp out, or an all-out. The more general complaints don't tell you very much, whether it's a fault, or just that traffic is busier for some reason.

Now, look at the junction below (well, two junctions):



The parts that have been coloured red in the picture are the detectors and inputs related to the traffic signals – in this case we have two junctions, over 20 on-crossing detectors, over 100 detectors and inputs between the two junctions.

Now, here's the thing: what happens when a detector goes faulty? If it's an on-crossing detector, the normal method of failure is 'active' – this extends the all-red period to its maximum configured value, which is the safer option. Similarly, a faulty VA detector on say, a side road would default to 'active' – this would ensure that the side road would get green, rather than allowing vehicles to be stranded on the side road. There are many types of detectors, all with similar strategies if they become faulty.

However, the downside of a faulty detector is that the side road gets an excessive amount of green time, the side road is demanded when there is no vehicle present, or traffic is held for a longer time on the all-red period following the pedestrian green man.

So, with our two junctions above, we have over 100 detectors and inputs which are used in the overall functioning of the junctions; if a detector becomes faulty, it could unnecessarily add to the overall delay to traffic.

Please bear in mind that Cumbria has over 200 sets of traffic signals in the county – a rough approximation is about 4000 detectors and inputs for all the signals installations in the county.

The question here is - if there a particular issue here to do with faulty detection, is that a big deal?

I'd suggest that, yes, it is – with the help of the guys at Aimsun, we've looked at quantifying the effect of a fairly minor traffic fault.

The effect of minor traffic signals faults on congestion and emissions

A study was published some years ago by Matthew Barth and Kanok Boriboonsomsin, the graph below is from that report, and relates vehicle speeds to vehicle emissions:

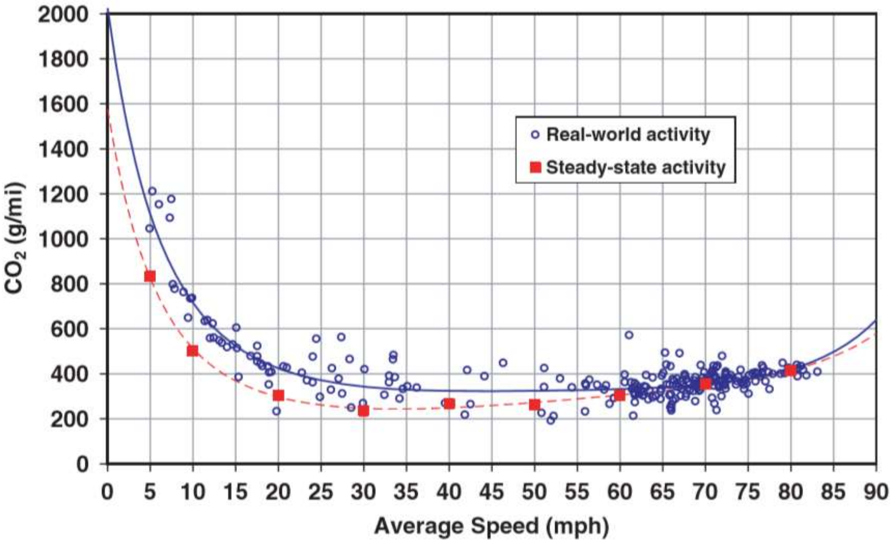


FIGURE 3 CO_2 emissions as a function of average trip speed.

Do you notice:

- the emissions are at a minimum from about 20mph onwards?
- If the average vehicle speeds reduce to just below 10 mph, the emissions are approximately double that at speeds of 20mph

So, if there are any issues (such as a faulty detector) which could be to the detriment of the efficient operation of the junction, there would be a consequent increase in vehicle emissions. The problem here is that a faulty detector isn't necessarily something that's obvious to the public.

So, where do we go from here?

Measurement of delay and emissions due to a signals fault

A junction in Carlisle was used as a trial site: for four mornings over a two-week period, we set an on-crossing detector to ‘faulty’. For the remaining weekday mornings of the trial, the site was set back to normal.

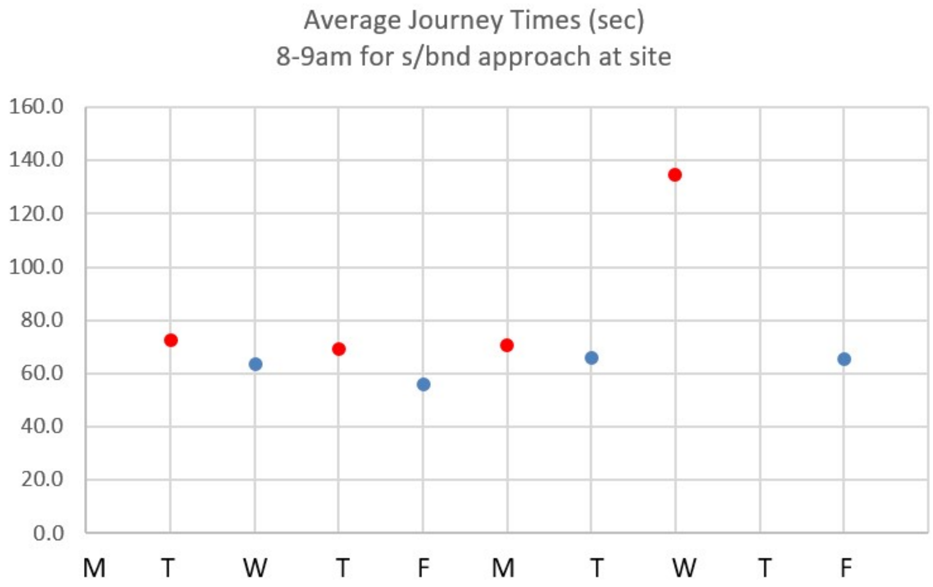
The ‘faulty’ on crossing detector would default to an active state, meaning that the pedestrian crossing time would be extended.

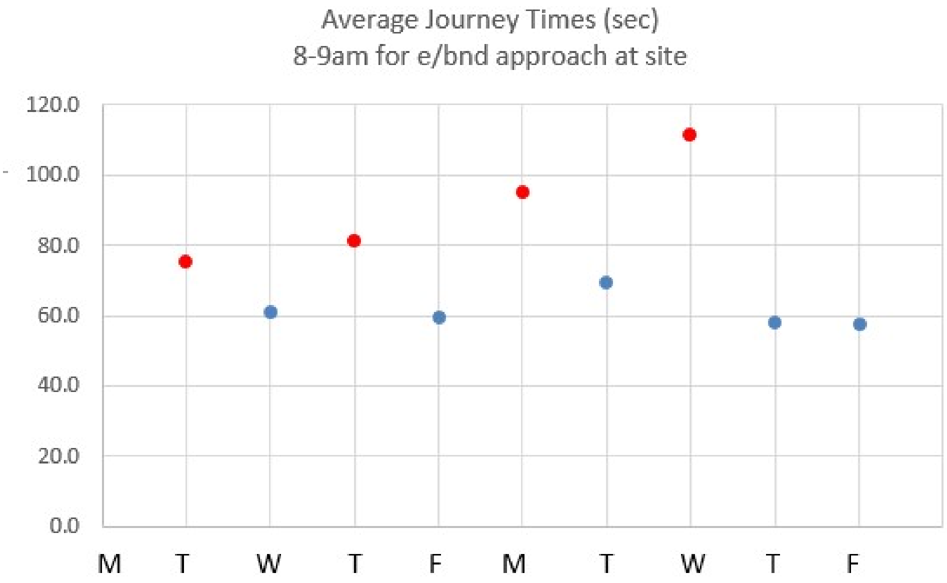
The morning journey time, queue lengths and traffic flows were measured over that two-week period, to see if there was a change to the overall efficiency of the traffic signals.

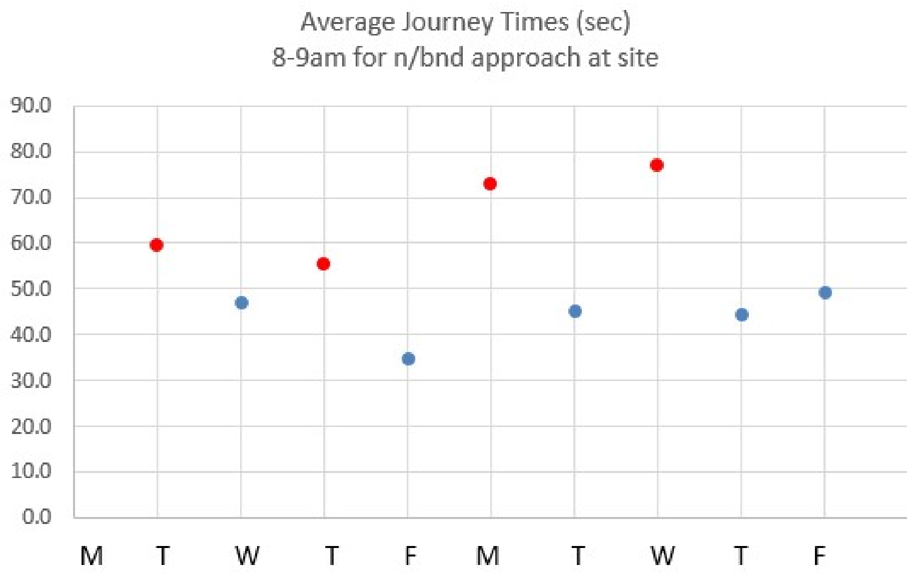
The results of the trial

This is a small trial experiment; the intention here is to show that there is an issue deserving further investigation.

The red dot indicates a day that the detector was set to faulty; the blue dot indicates a day with no detector faults.







Also, note there were no results on the first Monday, because of issues on site. Similarly, the southbound results for the 2nd Thursday have been omitted because of problems on site.

The results do seem to be consistent – on the days with faulty detection present, the journey times are longer on each approach.

Modelling of results

Aimsun have used the survey data in order to quantify the results. Their brief report is provided at the end of this paper. However, a broad summary of the results is as below.

We've compared the results of 'faulty' detection against the normal detection, summarising the results of the increase in emissions - other data could equally be considered, such as the lost time due to the faulty detector, or the increased fuel used.

					per hr	per 3hrs (=day)	**Per month (22 days)**	**per year (250 days)**
IEM Emission (All)	Normal Detection (g)	Faulty detection (g)	Diff (%)	Diff (g)	Difference (kg)		Difference (Tonnes)	
CO2	276945	296288	7%	19343	19.343	58.029	1.28	14.51
NOx	664	722	9%	58	0.058	0.174	0.004	0.044
PM	57.97	64.3	11%	6.33	0.00633	0.01899	0.0004	0.004
VOC	381.03	425.93	12%	44.9	0.0449	0.1347	0.003	0.034

The initial results for the one peak hour modelled have been extrapolated to indicate a day's emissions (I've assumed that to be equal to three peak hours). Factoring this up to provide say a month's equivalent emissions (assuming 22 working days), or a year's equivalent emissions (assuming 250 working days).

These results don't take into account any weekend traffic, just weekdays. Because of that, I'm suggesting that the figures I've used are possibly on the conservative side.

Discussion of results

The table above shows the increase in emissions because of a faulty detector; over a period of say, a month, the increase in CO2 is around 1.3 tonnes, or around 14.5 tonnes per year for that one junction.

The point I'm making here is that if a fault develops at a signals site, that will lead to increased delays (even from a minor one, such as a detector fault). As was pointed out earlier, reducing the average speed from say 20mph to just below 10mph (because of increased delays) could result in a doubling of the CO2 emissions.

Possible ways forward

There are three points I'd like to reiterate here:

- The public are unlikely to see and report a fault, unless it's a fairly obvious one, such as a lamp fault or an all-out;
- A detector fault at a site could lead to increased delays, but is unlikely to be reported by the public;
- Because of the fault, there could be an increase in emissions, as we've seen in our trial site.

So, what's the answer? How do I improve on this situation?

My take on this was to assume that no faults would be reported by the public. If the public do report a fault, not a problem, we'll look at it and do what's needed to resolve the situation.

Also, I'm not just reliant on faults being reported – my suggestion here is that emissions are now of such importance, that just to rely on the public isn't the best way forward.

What I have done is to look at the systems we already have in place, and use those to check for faults, on a routine basis. In Cumbria we have the UTC and RMS systems in place for a number of sites – UTC, in particular, seems to be an ideal system to check for faults - the UTC system will list what sites have detection issues, in addition we can use the stage timing monitor to see what's happening overnight to the site. It's possible to check the site remotely (via the handset link) to check on individual detectors - often we can clear the fault at the time, without any further problems.

Several years ago, our coverage of all the signals sites in Cumbria was just over 30% - the cost of UTC communications (using BT multi point lines) was so expensive it ruled out extending UTC coverage to any more sites. For example, it used to cost (in total) about £6,000 per year for the BT lines to the signals sites in Whitehaven and Workington, in the west of Cumbria.

However, the game changer was migrating across to digital communications, and employing wireless networks where needed – the same UTC links to Whitehaven and Workington now cost around £800 per year.

Because of this reduction in cost, we've installed UTC and Scoot to even minor locations, such as Ambleside, even to the point of using Scoot coordination on two pedestrian crossings, providing a real benefit – the cost of the one BT line to Ambleside is around £400 per year.

The picture below shows the UTC system installed in Whitehaven town centre – the cost of the scheme was relatively low (less than the cost of a small resurfacing scheme), and connects up six signals sites onto UTC, via the one BT broadband line and wireless networking to connect those sites. This was done primarily to monitor for faults, in addition it also enables Scoot coordination. The annual cost for the BT line is approximately £400 per year.

Whitehaven town centre UTC coverage using wireless networking

We now have around 75% coverage of all the signals sites in Cumbria, so we're able to monitor those sites on a routine basis for faults – it's now just a routine task we do, it takes about half a day to pick up any faults from UTC or RMS, clear any faults that we can, and pass the remainder on to our signals contractor to fix.

Ideally, I'd like to have 100% coverage of the signals sites on either UTC or RMS, with monitoring of future sites possibly being implemented as a result of Development Control or other funding streams.

The point here is to routinely trawl the traffic signals sites for faults and resolve any detection or lamp issues.

Also, since adopting this general method of looking at faults, there don't seem to be as many complaints coming in as there used to.

So, my suggestion here is that this isn't a 'big' idea, it's actually a fairly small idea. If, by routinely picking up detector faults we're able to improve on air quality, and it's something that can easily be done on a routine basis, then it must be worth considering.

I'd like to personally pass on my thanks to Rob Lewis and Martin Wright of Cumbria County Council, Richard Gibson of IDT Ltd and Gav Jackman and the team at Aimsun Ltd for all their help and support with this project.

Reference:

Barth, Boriboonsomsin (2010) 'Real-World Carbon Dioxide Impacts of Traffic Congestion', University of California

Etterby Junction Model

Authors: Jan Gondzio
Reviewer: Joan Roca
Date: 2nd August 2018
Version: V2

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1. Preface

Aimsun aim to further the use of modelling and simulation in all areas of transport planning, traffic management and intelligent transport systems.

We enjoy collaborating with new and existing partners through project work and occasionally undertake interesting pieces of work on a pro-bono basis where the business case is difficult or complicated to justify.

This study fitted the bill nicely and so we were happy to collaborate with Cumbria County Council and IDT to undertake a simple modelling and report exercise.

2. Introduction

Aimsun have developed a single junction model to evaluate the effect of faulty signal operation on a junction in Carlisle. The work has been done jointly with Cumbria County Council. The nature of the fault is that a detector does not perceive when pedestrians have cleared a crossing, therefore extending the intergreen phase to its maximum time of 15s, instead of roughly 6-8s in “normal” operation. The hypothesis is that this relatively minor fault results in an increase in delay at the junction and therefore an increase to fuel consumption and emissions. The purpose of the model is to verify the hypothesis and quantify the effects.

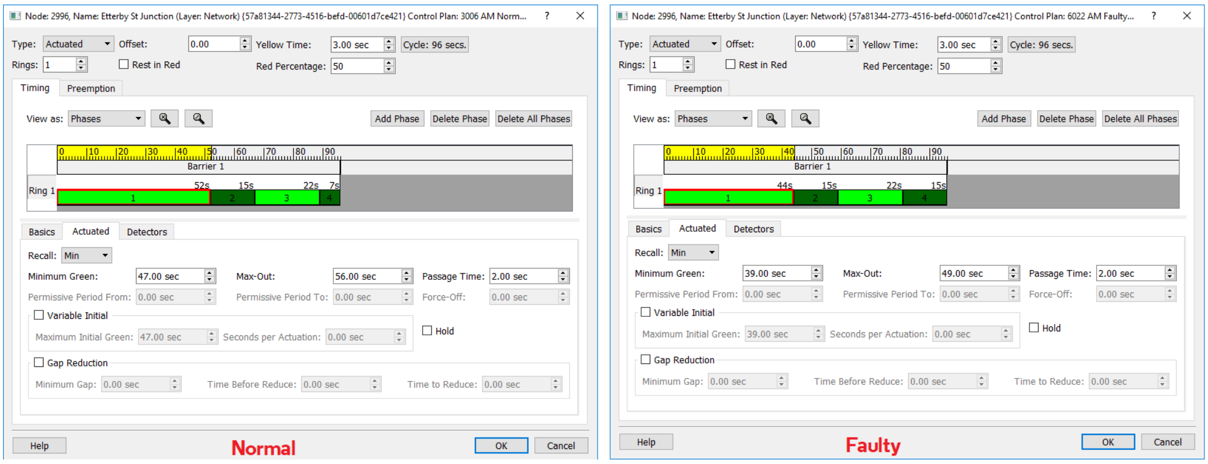
3. The Model

The model represents a 1-hour morning peak period of 08:00-09:00, based on turning count data at the junction. The Etterby St / Scotland Road / Stanwix Bank Junction has been coded using actuated signals to represent their operation based on detectors which adapt to the volume of traffic on the approaches. To represent realistic behaviour in the peak hour, the minimum and maximum times for each stage have been based on 25th and 75th percentile values of the average of four days of operation in either “normal” or “faulty” mode.

Two scenarios have been modelled:

- “Normal” – where the signals operate normally, with an average interstage time of 7s.
- “Faulty” – where the pedestrian detector is deemed faulty, extending the interstage to 15s in each cycle, accordingly shortening stage 1 of the signals.

The Control Plan of the signals is the only difference between the two scenarios. The two control plans are illustrated in Figure 1.


Node: 2996, Name: Etterby St Junction (Layer: Network) {57a81344-2773-4516-befd-00601d7ce421} Control Plan: 3006 AM Norm...

Type: Actuated
Offset: 0.00
Yellow Time: 3.00 sec
Cycle: 96 secs.
Rings: 1
☐ Rest in Red
Red Percentage: 50
View as: Phases
Ring 1: 1 52s, 2 15s, 3 22s, 4 7s
Recall: Min
Minimum Green: 47.00 sec
Max-Out: 56.00 sec
Passage Time: 2.00 sec
Permissive Period From: 0.00 sec
Permissive Period To: 0.00 sec
Force-Off: 0.00 sec
☐ Variable Initial
Maximum Initial Green: 47.00 sec
Seconds per Actuation: 0.00 sec
☐ Hold
☐ Gap Reduction
Minimum Gap: 0.00 sec
Time Before Reduce: 0.00 sec
Time to Reduce: 0.00 sec

Node: 2996, Name: Etterby St Junction (Layer: Network) {57a81344-2773-4516-befd-00601d7ce421} Control Plan: 6022 AM Faulty...

Type: Actuated
Offset: 0.00
Yellow Time: 3.00 sec
Cycle: 96 secs.
Rings: 1
☐ Rest in Red
Red Percentage: 50
View as: Phases
Ring 1: 1 44s, 2 15s, 3 22s, 4 15s
Recall: Min
Minimum Green: 39.00 sec
Max-Out: 49.00 sec
Passage Time: 2.00 sec
Permissive Period From: 0.00 sec
Permissive Period To: 0.00 sec
Force-Off: 0.00 sec
☐ Variable Initial
Maximum Initial Green: 39.00 sec
Seconds per Actuation: 0.00 sec
☐ Hold
☐ Gap Reduction
Minimum Gap: 0.00 sec
Time Before Reduce: 0.00 sec
Time to Reduce: 0.00 sec

Figure 1: "Normal" and "Faulty" Actuated Signal Control Plans

The demand remains the same in both scenarios and this is confirmed in the results.

4. The results

Outputs of emissions and fuel consumption have been collected and indicate an increase in the “faulty” signal scenario, as expected. A summary of key outputs for the whole modelled hour, for all vehicle types combined, are shown in Table 1.

Table 1: Key Results Indicators

Time Series	Normal	Faulty	Difference	Units
Delay Time	58.06	74.97	16.91	sec/km
Density	13.64	15.31	1.67	veh/km
Flow	2239	2239	-1	veh/h
Fuel Consumption	101.19	110.84	9.65	l
IEM Emission - CO2	276945	296288	19343	g
IEM Emission - NOx	664	722	59	g
IEM Emission - PM	57.97	64.30	6.33	g
IEM Emission - VOC	381.03	425.93	44.90	g
Input Count	2241	2241	0	veh
Mean Queue	10.98	14.60	3.62	veh
Number of Stops	0.70	0.81	0.11	#/veh/km
Speed	33.1	29.8	-3.3	km/h
Stop Time	48	63	15	sec/km
Total Number of Lane Changes	1164	1166	2	
Total Number of Stops	3744	4343	600	
Total Travel Time	32.53	36.50	3.97	h
Total Travelled Distance	910	910	0	km
Travel Time	128	145	17	sec/km

Table 2 gives a breakdown of CO_2 emissions by route between the main junction approaches.

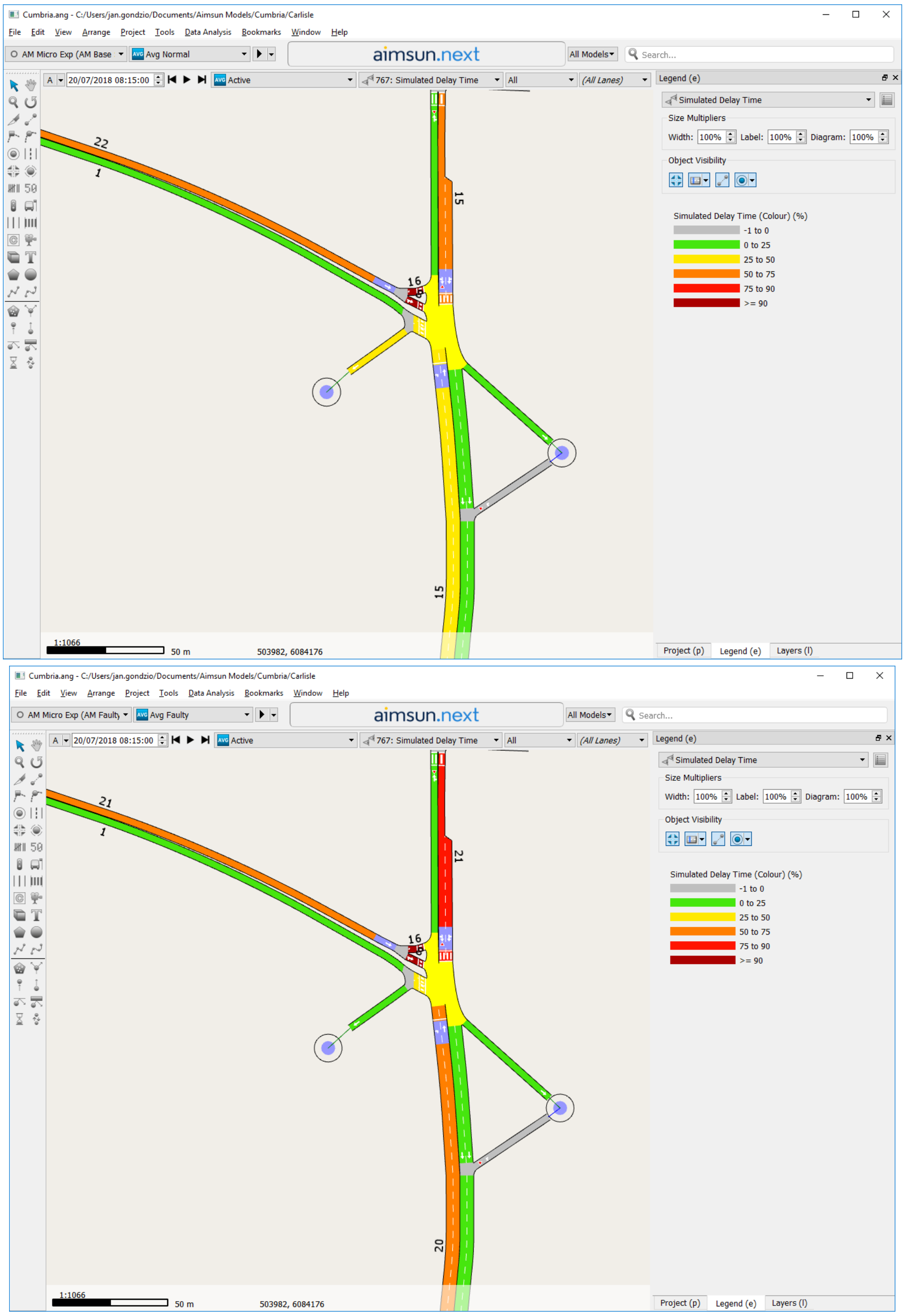
Table 2: CO_2 Emissions by Route

					IEM Emission - CO2 (g)			**IEM Emission per vehicle km - CO2 (g/veh/km)**		
Route	From	To	Vehs	Length (km)	Normal	Faulty	Diff	Normal	Faulty	% Diff
A-C	Scotland Road	Stanwix Bank	770	0.358	87,459	95,547	8,088	317	346	9%
C-A	Stanwix Bank	Scotland Road	664	0.357	75,246	82,273	7,027	317	347	9%
E-A	Etterby Street	Scotland Road	34	0.418	2,679	2,927	247	188	206	9%
A-E	Scotland Road	Etterby Street	60	0.444	2,595	3,006	412	97	113	16%
E-C	Etterby Street	Stanwix Bank	328	0.525	39,897	42,639	2,743	232	248	7%
C-E	Stanwix Bank	Etterby Street	312	0.515	9,902	10,842	940	62	68	9%
SUM			2168	2.617	217,778	237,235	19,457	38	42	9%

An increase in delay is observed, again as expected, and illustrated in Figure 2.

5. Summary

In summary, the modelling supports the hypothesis that a faulty signal generates an increase in delay, which in turn increases emissions and fuel consumption at the junction.



Cumbria.ang - C:/Users/jan.gondzio/Documents/Aimsun Models/Cumbria/Carlisle

AM Micro Exp (AM Base | Avg Normal | 20/07/2018 08:15:00 | Active | 767: Simulated Delay Time | All | (All Lanes)

Width: 100% Label: 100% Diagram: 100%

Cumbria.ang - C:/Users/jan.gondzio/Documents/Aimsun Models/Cumbria/Carlisle

AM Micro Exp (AM Faulty | Avg Faulty | 20/07/2018 08:15:00 | Active | 767: Simulated Delay Time | All | (All Lanes)

Width: 100% Label: 100% Diagram: 100%

Figure 2: Delay Time Comparison between normal (top) and faulty (bottom) scenarios