Better signals using co-operative ITS data

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Appendices

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APPENDIX 1

Literature Review

1-1 DFT Studies

Firstly, work previously undertaken for DfT in this area was examined. The TRL report PPR041[1] from 2006 is somewhat superseded in terms of technology but the principles of co-operative ITS they examined remain very sound. It concluded that there are real benefits in improved efficiency of junction signalling and green waves. Some were from safety benefits outside the scope of this work, but key use cases were to tune the parameters of traffic systems, identify exit blocking, temporary traffic signals and other use cases.

This also identified benefits estimates for the UK as a whole. Extra data from co-operative vehicle data e.g. for origin destination movements could be worth £8-£80m a year for the UK, with similar values from reduced emissions. Specifically probe vehicle information could be used to improve saturation flow estimates (a key parameter in signal plan generation) worth around £60m per annum plus small accident savings. A higher benefit of £180m a year was identified from identifying the causes of downstream exit blocking and up to £27m for temporary signals. It did not however determine the cost savings from co-operative over physical infrastructure.

This study sets the scene well for this project. It highlighted that for the UK there are a variety of different "pots" of benefit from co-operative data. Not all of these (e.g. identifying and fixing the causes of exit blocking) need to be in real time – use of historic data over time might give as useful benefits. It also highlighted that the architecture for how the data is to be used in a UK traffic control system is of vital importance, and that the penetration of equipped vehicles (especially V2I) will take time.

A previous TTRIG[2] study also highlighted the challenges faced by a local authority in deploying C-ITS and highlighted the need for "light touch" and hybrid solutions to enable deployment in the UK.

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1-2 Purdue and Dynniq Work

The next stage was to examine published work on the elements above. This was aided by Robbin Blokpoel of Dynniq in the Netherlands and Darcy Bullock of Purdue University is the US kindly providing their latest works with many useful references. Bullock's paper[3] looked at how detectors could be replaced by probe data and showed a summary of selected approaches. The key was that all previous approaches need high levels of penetration of connected vehicles – around 20% or so. His paper then usefully explored how signal optimisation could occur with a much lower penetration and showed early examples with as little as 0.1% penetration – far less than that of current INRIX data in York which is around 1%. This high sample size is required by some approaches that simply replace loops with vehicle data and so require accurate flow data.

By using standard signal phase timing and offset techniques by simulation Bullock showed an off-line approach for offset optimisation using real world data. This off-line approach uses historic data to tune signal settings by measuring vehicle arrival profiles. This work was then extended to look at INRIX data in a subsequent paper[4]. This focusses on the fit between green windows for traffic and vehicle arrivals using individual vehicle data sourced from INRIX to develop a "Purdue co-ordination diagram" that allows offset optimisation using historic data.

In contrast, Blokpoel[5] reported the outputs of the EU Colombo project and looked at both probe and FVD vehicles' data, as well as combinations with existing infrastructure. This looked also at low penetration rates and developed an algorithm that considered reduction in delay across the junction as a "control theory" type problem to reduce total delay. This means that link based journey times such as that already available from INRIX could be used rather than point data. A later paper[6] showed that co-operative data plus a fall back to a stop line sensor could reduce delays by up to 33.6%, so bringing the entry detector loop approach of SCOOT to junctions without the cost of extra detectors. Further discussion with the author showed this could also be applied to SCOOT. He said:

I do see a high potential for changing SCOOT parameters based on INRIX data.

A further paper[7] showed the work of the Colombo project using the Co-operative Awareness messaging (CAM) approaches likely to be used in DSRC V2I approaches for individual vehicles. Another paper from Colombo[8] showed potential emissions reductions from new techniques using co-operative detection (e.g. 8% reduction in Co2).

1-3 Other sources

As well as the above two key sources of the state of the art in European and the US, we also examined other project work. Sawada[9] showed that in Japan only around 50% of the 15,000 signals in Tokyo are adaptive – and that there could be benefits from moving fixed time to more central control if probe data were available thereby avoiding the cost of adaptive infrastructure. As in the TRL report, they suggest benefits from using probe data to identify poor performance off line using lane specific and OD related data that cannot be obtained from sensors. This off-line use of data is an easy first step requiring no change in architecture but with potential quick wins.

Huang[10] looked at the connection between using SPaT equipped vehicles to change demand profiles and use of data from them. This highlights that when conditions are appropriate, SPaT may "make traffic fit signals" whereas these algorithm approaches "make signals fit traffic". Together, they could be a useful combination. A sister T-TRIG project called CROCS is investigating how existing UK traffic control systems can support SPaT and hence there is synergy (although CROCS' scope only considers links to the vehicles, and this project data from them)

Day[11] examined use of Bluetooth data (similar to V2I data) to measure journey times and showed it was possible to measure wasted green time from poor progressions. This is important as it shows that low penetration data used en masse for historic assessment can be valuable, and that V2I penetration may not be an issue if Bluetooth is used. Somers[12] and Herring[13] both looked at measures of performance using sparse data. Neumann[14] examined use of probe data with low penetrations (2%) to more accurately measure the queue length at a junction (a process undertaken in SCOOT for example by a modelling approach).

Box[15] showed some of the various approaches to algorithms and a simulation based approach. This is useful as it looks at UK approaches specifically. It also highlighted various patents in this area which may impact on the IP of new ideas and hence their open deployment. Hamilton[16] also highlights that for the UK the potential for traffic signals learning from probe data and for a more

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holistic approach needs to be balanced with the change from a "data sparse" to "data abundant" traffic network.

We also reviewed many other papers which were less relevant, as they either assume 100% penetration of probe vehicles (which is impractical) or do not align well with UK conditions or approaches. Often, they require a "big bang" change e.g. removal of all existing detectors which is simply impractical for the UK. Many papers focus on the communication of data from vehicles rather than the use of the data to achieve policy aims.

Appendix 1 Sources and References

1 TRL PPR041, Cooperative road traffic signalling - potential costs, benefits and data exchange requirements, Transport Research Laborartory, 2006

2 CAV-PAS, SG transport Innovation, march 2015

3 Darcy M Bullock – paper 16=001 16-0112 Opportunities for Detector-Free Signal Offset Optimization with Limited Connected Vehicle Market Penetration: A Proof-of-Concept Study

4 Li, Howell, C.M. Day, D.M. Bullock. "Virtual Detection at Intersections using Connected Vehicle Trajectory Data." IEEE International Conference on Intelligent Transportation Systems, November 2016.

5 Traffic control using probe vehicle data, Blokpoel and Turksama, 10th ITS European Conference Helsinki 2014

6 Data fusion of cooperative data with adaptive traffic control, Colombo project

7 Traffic management based in vehicular communication at low equipment rates, Krajzewicz and Blokpoel, ITS World Congress Paris 2015

8 Emission optimised control, for isolated intersections, Blokpoel and Hasuberergm ITS 2019

9 Efforts to optimize signal control using probe data. Sawada and Yamaguchi ITS World Congress

10 Huang et al, SPaT and active traffic management strategies for oversaturated signalised intersections. ITS World Congress Bordeaux, 2015

11 Day et Al. Roadways System Assessment using Bluetooth based vehicle ID. Purdue University 2012

12 Somers, A. Using GPS probe data for traffic network optimisation. CAITR 2004

13 Herring et 1l. Estimating arterial traffic conditions using spare probe data

14 Neumann, Efficient Queue length detection

15 Box et al. Signal Control suing vehicle localisation probe data, UTSG 2010

16 Hamilton et al. The evolution of UTC: Changing Policy and Technology: Transportation Planning and technology, 2013,

APPENDIX 2

Meeting Customer Needs

The following table shows our analysis of the opportunities by examining each of the customer requirements in table 1 and checking if;

- customer requirement is already supported by UG405, the UK traffic controller standard or by the UTMC approach. In many cases for fixed time plans this already is in place
- traffic controllers available from Dynniq can already support the need
- communications equipment and services available from IDT can support the need
- INRIX's FVD services can support the need

In the table below, green shows an off the shelf availability, amber implies some development work needed that is short term, and red implies no current support for the idea.

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Reference	Complexity**	Requirement from COYC	Already standard in UG405?	Dynniq Controller can do this?	IDT can support this	Inrix data can support this	Gap to fill and work to do
1	S	Offline testing of current plans vs congestion using analysis of performance	NA	NA	NA	Yes - Inrix Analytics platform can be used to investigate performance.	Need to think of how Transit/ linsig might be used with FV data
2	S	Offline decisions as to best strategy to use (eg SCOOT to MOVA, SCOOT to FT)	NA	NA	NA	Yes - Inrix Analytics platform	May need "before and after" testing
3	S	Online switching of strategy based on DSRC or INRIX data (eg FT to VA) from instation process that instructs controller	Yes	If the controller is simply receiving instruction from the UTC system then, yes.	Yes. IDT can provide raw JT data (from suitably configured roadside devices) to central decision making systems	Yes - Inrix real-time speed API can be used as a source for trigger events.	Input route into UTC needs to be developed for a tactical approach (see 4) Strong market potential
4	C	Emulating a loop (presence or SCOOT LPU) from processed INRIX or DSRC eg to replace VA loops for off peak	No but TR2523 allows emulation	Yes, probably via our Chameleon which would need a minor amount of development depending on interfaces, etc	N/A	No - INRIX trips data not available in real-time. INRIX do not currently have a product that could replace a VA loop.	Processing probe data to emulate loop may be a gap. Sample size for loop emulation may be the challenge (esp DSRC)
5	C	On line changing of fixed time plans based on triggers from INRIX data	Yes	Not yet	N/A	Yes - Inrix real-time speed API can be used as a source for trigger events.	Taking an "alert" from INRIX and changing plan is a gap
6	C	On line changing of plans based on triggers from DSRC data	Could set a general-purpose reply bit	Yes	Yes. See above.	NA	Input route into UTC needs to be developed – processing DSRC to take an action. Sample size an issue
7	C	Support CROCS Schema	NA	As an open standard, it should be supported	Yes. iMesh will transmit SpaT/MAP messages received from CROCS controllers	NA	Controller or device development to output CROCs

Reference	Complexity**	Requirement from COYC	Already standard in UG405?	Dynniq Controller can do this?	IDT can support this	Inrix data can support this	Gap to fill and work to do
8	C	Use FVD data to change timings in temp traffic signals instead of / as well as presence detectors	Yes, if timings fixed. Vehicle presence needs more assessment	Maybe overkill to use a Dynniq controller for this?	NA	Yes - Inrix real-time speed API can be used as a source for trigger events.	Need to think about how to trigger this and sample size
9	C	Process multiple inputs from cloud based services eg Dynniq emissions dashboard and detectors to change strategy	Yes	Yes	NA	Yes - Inrix real-time speed API can be used as a source for trigger events.	UTMC may provide already... but without UTMC; Input route into UTC needs to be developed
10	VC	Process Dynniq and Perdue algorithms to change plans offline or change stage in real time	Yes – needs instation processes	Not yet	NA	For Dynniq using link speeds, yes., For Purdie, maybe for offline – to be confirmed. But not yet for real time	Gap in processing but output would be similar to online changing of plans?
11	VC	Process multiple inputs to change tactics (eg stage, vehicle priority for bus based on occupancy	Yes – needs instation processes	Assuming all of the tactics are "standard" all of the above requirements are already met then, yes	NA	Only from existing API and analytics	Input route into UTC needs to be developed Low latency input; Input route into UTC needs to be developed
12	EC	Full co-operative signal control with digital controller and digital inputs for both strategic and tactical control	No	No	NA	Not yet.	The end destination

** - Complexity - S = Simple; C = Complex; VC = Very Complex; EC = Extremely Complex from COYC

APPENDIX 3

INRIX data availabity for York (2017)

Data Set	Historic	Real-time
Corridor Analysis	Yes	No
Segment Speeds	Yes	Yes
Trips	Yes	No
Vehicle Positions (points)	Yes	No

DSRC Data availability table potential (future)

Data Set	Historic	Real-time
Corridor Analysis	Yes	Subject to penetration
Segment Speeds	Yes	Subject to penetration
Trips	Yes	Subject to penetration
Vehicle Positions (points)	Yes	Subject to penetration

Bluetooth data availability table (not for York) (2017)

Data Set	Historic	Real-time
Corridor Analysis	Yes	No
Segment Speeds	Yes	Yes
Trips	Yes	No
Vehicle Positions (points)	No	No

APPENDIX 4

Cost Benefit Assessment

Step ONE; convert TfL benefits to York network	**Vehicles**	**Source**
York A59 AADT	10751 15336 18141	From DfT count sites at either end and middle of scheme area
Mean Value	14742.7	
London major road AADT (urban)	26100	DfT Table TR0302
Flow factor	0.564853	York flow is 56% of Tfl's
Step TWO; convert TfL savings to York (Money)	**£**	**Source**
Cost savings per TfL junction	£90k VOT(2009) £108k VOT (2016)	(1) ONS inflation calculator
Cost savings per York junction Cost savings on COYC scheme	£61.004 £488,033	56% of TfL value 8 Junctions

Step THREE; profile of costs and benefits	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	**Notes**
Cost	£300,000	£30,000	£30,000	£30,000	£30,000	£30,000	£30,000	£30,000	£30,000	£30,000	10% of costs for data
Ben	£488,033	£488,033	£488,033	£488,033	£488,033	£488,033	£488,033	£488,033	£488,033	£488,033	Assume no traffic growth
PV	£188,033	£458,033	£458,033	£458,033	£458,033	£458,033	£458,033	£458,033	£458,033	£458,033	
Dsct											
NPV	£3,548,411										Treasury Green Book datasheet July 2016 - 3.5% discount
PVC	£510,368										
PVB	£4,058,799										
BCR	**8.0**										

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Step FOUR; Sensitivity testing	**Indicator**	**Value**
If congestion period times are 50% higher in TfL than York, reduce benefit by 50% (based on hypothesis)	PVB PCV BCR	£2,029,389.35 £510.368.00 **4.0**
If traffic growth means congestion savings increase by 25%	PVB PVC BCR	£5,073,473.38 £510.368.00 **9.9**

Step FIVE Outputs	**BCR**	**Period**
Lower bound BCR	**4:1**	over ten years
Best estimate bound BCR	**8:1**	over ten years
Upper bound BCR	**9.9:1**	over ten years
(TfL has shown 12:1 over ten years)		

Additional Information
Sanity Check; Tfl has reported 12:1 BCR, but would have higher costs If constants are the same but flow double, a 6:1 ratio is in the right Order
Abbrviations; NPV - Net Present Value PVC - Present Value of Costs PVB - Present Value of Benefits BCR - Benefits / Costs Ratio
Note (1) - http://www.itsinternational.com/sections/cost-benefit-analysis/features/tfl-expands-scoot-adaptive-traffic-management