World Transport Policy and Practice

Volume 22.1/2

May 2016

ISSN 1352-7614

Measure No.16: Traffic Management and Control

Photographer/Copyright: Harry Schiffer. http://eltis.org

Applications of technology that help to manage the movement of people in urban areas.

These interventions can help flows around city transport networks. They include urban traffic control systems (UTC), traffic signals that respond to specific modes (e.g. buses or cyclists), the use of cameras to protect dedicated lanes or manage junctions and variable message signs (VMS) providing dynamic instructions to vehicles.

16.1 Context and background

This measure considers a range of interventions that are concerned with the management of vehicles, and travellers on transport networks – particularly traffic on the road network.

In more detail, these systems are:

1. Urban Traffic Control (UTC) systems: UTC systems are linked and coordinated networks of traffic signals. Traffic flows on junction approaches are monitored in real time and signal timings are continuously optimised across the network (according to traffic conditions) through a centralised processing algorithm such as SCOOT (Split Cycle Offset Optimisation Technique). UTC systems are often set up to minimise delay to motorised vehicles. However, they may

Key messages:

- Urban Traffic Control systems (UTC) can be expected to improve network efficiency by reducing delays to vehicles. This can have additional benefits in reducing fuel use and emissions (although evidence here is limited).
- Economic benefits are calculated mainly on the basis of time savings. These savings may be specifically for public transport users, cyclists, or for general traffic
- Providing priority to public transport or bicycles through UTC can contribute to significant journey time savings without compromising journey times for other road users.
- Automatic systems to monitor bus lanes and signalized junctions have been shown to improve journey times, reduce infringements and reduce collision rates at junctions.
- Investment payback periods for bus priority measures are seen to range from 3 months to 2 years in the examples reviewed.
- Variable Message Signs (VMS) can divert some traffic (although they are less likely to be effective in heavily congested networks).
- VMS has the potential to contribute to time savings in public transport corridors, but evidence is currently limited here.

Potential interventions

- Urban traffic control systems (UTC), that focus on maximising the throughput on the network – helping to reduce congestion and thus pollution
- Traffic signals that give priority to, and respond to specific modes (e.g. buses or cyclists),
- Cameras used to enforce the protection of dedicated bus / cycle or high-occupancy lanes or used to manage junctions to ensure free-flow
- Variable message signs (VMS) which can provide dynamic instructions to vehicles (for example highlighting congestion, alternate routes, parking availability etc.)

also be optimised to minimise fuel consumption and to reduce emissions or to provide selective priority to public transport or cyclists.

2. Selective vehicle detection at traffic signals: Various types of 'Selective Vehicle Detection' (SVD) system can be employed at signalised junctions to provide additional priority to cyclists or users of public transport. These systems operate by detecting bicycles, buses or trams on the approaches to stop lines (usually through inductance loops for cyclists or the use of GPS tracking systems in the case of public transport) and then either re-call or extend green times. The objective is to minimise the delay to cyclists or public transport at junctions without significantly compromising journey times for other road users.

3. Enforcement of bus lanes using technology: Bus lane infringements (parking violations for example) can have a serious impact on bus reliability. Highly visible automatic detection systems (cameras with automatic number plate recognition for example) can be installed to discourage drivers from entering the bus lane. The objectives of such systems are to reduce infringements and to improve public transport journey times and reliability.

4. Camera enforcement at signalised junctions: Similarly, cameras may be installed at signalised junctions to reduce red light running and collision rates.

5. Removal of traffic signal control: Proponents of 'shared space' style traffic management (see measure 22) argue that 'over control' of traffic at junctions, through the incremental introduction of signals, can have the unintended consequence of increasing delay to pedestrians and vehicles. In certain circumstances, the removal of traffic signals may meet objectives to increase junction efficiency (reducing delay to all road users) and to improve the urban environment (through the removal of unnecessary street furniture).

6. Variable Message Signs (VMS) in urban areas: VMS may be employed in urban areas to warn drivers of incidents, delays or to provide comparative information on journey times (on alternative routes or modes in the case of park and ride). The objective is usually to influence route choice in some way to reduce congestion, delays and to improve overall network efficiency.

16.2 Extent and Sources of Evidence

This review draws on 19 sources which, in the main, report on the impacts of a single intervention employed in a case study city. The single case studies have been supplemented by two meta-studies[1,2] to illustrate the wider applicability of the findings. One meta-study reports on the impacts of bus priority[1] at traffic signals across 24 cities around the world, while the second2 provides a comparative review of VMS system trails conducted in eight European cities. Indeed, seven of the sources have been generated by various EU funded programmes, which either commissioned a literature review or alternatively field trials of one of the traffic control measures identified in the introduction. While the majority of the cases consequently relate to an EU city, results from the USA, Japan, New Zealand and Australia are also discussed. Evaluation reports have typically been authored by academics or consultancies (and published on EU programme websites such as CIVITAS.eu) or alternatively results have been reported in academic journals or conference papers. Sources from the last five years were readily available, but the review has also relied on some good quality evidence from academia which is now over ten years old, particularly in relation to VMS[2] and bus priority at traffic signals[3].

16.3 What the Evidence Claims

The review presents evidence in relation to the types of intervention defined in the introduction.

16.3.1. Urban Traffic Control systems and fuel consumption

UTC systems are often set up to minimise delay to vehicles by extending green times where there is highest demand and by using signal offsets along arterial corridors to create 'green waves' (where successive junctions provide green as traffic approaches) to maintain flow. However, they may also be optimised to minimise fuel consumption and to reduce emissions. In theory, fuel consumption can be reduced by tuning signal timings to limit the need for drivers to stop at junctions, reducing delays and encouraging moderate speeds to be maintained along links in the network.

Stevanovic et al[4] evaluated new methods of optimising signal timings to reduce emissions using observed data on traffic flows through a network of 14 signalised junctions in Park City, Utah, USA. Their method of evaluation was based on micro-simulation modelling of signal timings rather than on observations in the field. Nevertheless they estimated that employing signal timing optimisation algorithms that specifically seek to reduce fuel consumption, could be expected to contribute to a 1.5% reduction in fuel consumption overall.

A field evaluation of an Adaptive Traffic Signal Control System implemented in Aalborg, Denmark[5] (along a 1.7km section of the ring road which included eight junctions), found that fuel consumption was reduced by 2.45% overall (based on calculation rather than on observation). This was attributed to smoother driving and a reduction in very low speeds.

Overall, UTC systems have been shown to be highly effective at managing capacity – improving traffic flow and reducing delay. For instance, an installation of SCOOT in Toronto across a network of 75 junctions was shown to achieve an 8% reduction in travel time, a 22% reduction in vehicle stops, a 17% average decrease in vehicle delay, a 5.7% reduction in fuel consumption, and a 5.0% reduction in carbon monoxide emissions[6].

Perrett and Stevens[7] performed a cost benefit appraisal of UTC systems in UK cities. They estimated a benefit-cost ratio of 7.6 over a five year appraisal period based on the introduction of five new systems in medium sized cities. Their analysis included time savings, changes in vehicle operating costs and changes in pollution costs. An important caveat, however, when considering UTC systems in the context of Sustainable Urban Mobility Plans is that signal optimisation across networks is intended to make the system more efficient overall for motor traffic, and hence encourages more motor traffic use. This can be counter to sustainable mobility objectives.

16.3.2. Bus priority at traffic signals

Some have suggested that UTC systems tend to be configured to minimise delay to general traffic, when they should instead be optimised to meet the more socially equitable objective of minimising overall delay to people1. A consequence is that those choosing not to travel through urban areas by private car may not be afforded an appropriate level of priority at signalised junctions. To address this issue, various types of 'Selective Vehicle Detection' system can be employed at signalised junctions to provide additional priority to users of public transport.

The International Association of Public Transport (known as UITP) commissioned a review of 'Bus Priority at Traffic Signals around the world' in 2008[1]. The impacts of SVD systems installed in 24 cities (mainly within Europe, bus also including Japan, New Zealand, Australia and the USA) were collated. The following impacts were observed:

- Delay savings of between 3 and 11 seconds per bus per junction;
- Travel time reductions of between 2% and 25%; and
- Patronage increases of up to 42%.

The level of benefit derived was noted to be constrained by the overarching policy framework rather than on the technical capability of SVD systems per se. For example, in some cities, the level of priority afforded to buses at signals was limited by wider objectives to maintain capacity for general traffic. The examples reviewed in Europe were shown to repay their investment costs within three to 16 months of operation.

Hill et al[8] evaluated the application of bus priority at junctions along a single corridor in Cardiff, UK using the SCOOT UTC system. Three configurations were compared: SCOOT with no bus priority, SCOOT with priority enabled for all buses and SCOOT with priority enabled for late buses only. Journey time savings of 3% were observed under priority to late buses only, rising to 4% under priority to all buses. In peak periods, journey time savings were shown to increase to 14-15% under both scenarios. Associated delays to general traffic were not found to be significant.

The EU commissioned INCOME (INtegration of traffic COntrol with other MEsures) project[3] evaluated priority measures for buses in four European cities (London (UK), Gothenburg (Sweden), Turin (Italy), and Piraeus (Greece)). The implementation of bus priority at junctions through UTC systems was shown to reduce journey times by four to 10% in London, five to 15% in Gothenburg and three to 16% in Turin. Other studies of sites with lower flows[9] were shown to generate journey time savings of up to 80%. Economic appraisals of the trial sites indicated pay back periods of less than two years.

Gating: UTC systems can also be used to improve journey times for buses by holding traffic at signals outside of central urban areas and then gating traffic into the central area at a rate than can be accommodated by the network. The objective is to improve flow through space limited central areas by moderating traffic throughput. Bus lanes are required on the approaches to gated junctions to avoid buses being delayed in queues. A trial of a gating system implemented in Twickenham, UK demonstrated a statistically significant journey time saving of 13% for buses[3]. Delays to general traffic as a consequence of the scheme were not found to be significant.

16.3.3. Enforcement of bus lanes using technology

The city of Bologna, Italy identified parking infringements in bus lanes as a major cause of delays to public transport, as well as contributing to wider congestion problems (through for example, illegal parking along narrow city roads)[10]. A mobile camera system with Automatic Number Plate Recognition (operated by the police department) was installed along two bus routes in 2008 and 2010. The system was shown to contribute to an 80% reduction in parking in the bus lane along one route. The reliability of bus journey times consequently improved (indicated by a reduction in journey time variability), particularly during the highly congested Christmas period (December). Journey times also reduced by five per cent along one route (route 13), but were not significantly changed along the other (route 14).

16.3.4. Bicycle priority at traffic signals

1. Green waves: Signal offsets along arterial routes can also be optimised (through UTC systems) to generate 'green waves' for cyclists. In this case, offset times (between green aspects at successive signals) are calculated using average cycle speeds as opposed to average vehicle speeds. Stopping is a major penalty for cyclists (given the effort involved in regaining momentum) and the objective of green waves is to reduce the number of stops along a link and to reduce delay. A similar affect can be achieved at isolated junctions by installing inductance loops at junctions to detect approaching cyclists. Cyclists are then given a green signal as they approach. Ryding[11] (cited in Knight et al[12]) evaluated a 'green wave' system of [13] interlinked signals in Copenhagen. Average cycle speeds were shown to increase by 5km/hr resulting in a saving of 2.5 minutes over the link. The number of stops required was also shown to reduce (by up to a maximum of six stops). Journey times for other vehicles were only found to increase slightly by (four seconds).

2. 'All green' stages: 'All green' stages for cyclists (where all other traffic movements are halted) have been employed to reduce potential for collisions between cyclists and other vehicle types. Wolfe et al[13] (cited in Weighland[14]) evaluated a junction in Portland, USA and found that 78% of cyclists crossed the junction illegally before the introduction of an 'all green' stage (implying a safety risk) and this reduced to 4.2% after the introduction of the all green stage. A cost benefit analysis of a similar configuration in Davis, California (USA)(by Korve and Niemeier[15], cited in Knight et al[12]) indicated that the safety benefits outweighed the costs associated with increased delays to other vehicles.

3. Priority in inclement weather: There have been trials in the Netherlands of detection systems to give additional priority to cyclists at traffic signals in wet weather. The objective is to reduce the need to stop and to reduce traffic signal violations by cyclists in inclement conditions. Evidence is limited, but an evaluation of the Dutch trial by Harms[16] (cited in Knight et al[12]) indicated significant reductions in both delays to cyclists and the number of cyclists running red signals during wet weather.

4. Gating at junctions: Gating can be employed to hold general traffic behind cyclists (waiting in advanced stop reservoirs) at junctions. This provides an opportunity for cyclists to enter junctions ahead of other vehicles and reduces the chance of conflicting movements (e.g. left turning vehicles conflicting with cyclists heading straight on in a UK context). A cycle gate was installed at at Bow Roundabout in London - a collision hot spot. Although a detailed evaluation was unavailable, Transport for London[17] reported that "the eastbound cycle early-start has been effective in reducing the risk of conflict with vehicles turning left".

5. Push button controlled bicycle and pedestrian (Toucan / Puffin) crossings: Bicycle and pedestrian phases are commonly used to provide opportunities for non-motorised users to negotiate road crossings. In cases where crossings are staggered, pedestrian / cycle signals can be offset such that users receive a green phase immediately on entering the central reservation to reduce delays to non-motorised users. Alternatively, staggered crossings can be replaced with single crossings. Maximum wait times for pedestrian / cyclists green phases (on requesting a crossing) can also be pre-programmed into signal controllers to minimise wait times at the roadside. Whilst such initiatives have been documented in good practice guides[12], no evidence was identified on their effects.

16.3.5. Camera enforcement of signals

Signalised junctions may be enforced through the installation of cameras (either automatically through ANPR or through manual monitoring of data feeds). The objective is usually to reduce collision rates at junctions. An evaluation of a system implemented in Bologna, Italy[18], demonstrated a 21% reduction in collisions and a 28% reduction in injuries at signalised junctions after installation of enforcement cameras (comparing the 2008 baseline year to 2011 when the full system had been rolled out). A cost benefit analysis was performed to quantify the benefits of these collision and injury reductions. Sensitivity tests indicated potential Net Present Values for the scheme of between 36,000,000 and 51,000,000 Euros over a 17 year appraisal period.

16.3.6. Removing traffic signal control

It is suggested that, in certain circumstances, the removal of traffic signals may increase junction efficiency and improve the urban environment (through the removal of unnecessary street furniture). This was demonstrated in trials conducted in Portishead and Bristol, UK[19].

The Portishead trial involved switching off signals at a quite complex, heavily trafficked junction (handling 1500 pcu/hr) for a period of four weeks (in 2009). Queues and delays were shown to reduce by 50% and the increase in capacity led to a growth in demand of 20% to over 2,000 pcu/hr. Average pedestrian crossing times were also shown to reduce by 20%. The success of the trial led to the signals being permanently switched off. Similar results were observed at one week trials conducted at two low traffic, high pedestrian flow junctions in Bristol city centre. Queues and delays were observed to reduce by between 30% and 40% and pedestrian crossing times also reduced. However, at one location in Bristol, two thirds of survey respondents felt that the junction was safer and easier to use under signal control.

16.3.7. Variable Message Signs in urban areas

Variable Message Signs (VMS) may be employed in urban areas to influence route choice in some way to reduce congestion, delays and to improve overall network efficiency.

Chatterjee and McDonald[2] reviewed evidence from VMS field trials implemented in the late 1990s across eight European cities (Valencia (Spain), Southampton, Bristol and London (UK), Lyon and Toulouse (France), Turin (Italy), and Piraeus (Greece)). Trials were sponsored by the EU under the 'Transport Sector of the Telematics Applications' programme. The VMS systems were evaluated through a survey of drivers passing VMS signs to measure their awareness of information and responses to this, monitoring traffic flows on VMS routes and potential diversion routes and the use of simulation modelling.

In cases where just one VMS sign was installed, only one third of passing drivers noticed the information. This increased to 89% of drivers in cases where several signs were available along a route. VMS information was found to be legible to drivers, particularly if simple text (rather than symbols) was employed. 80% of those noticing the information reported being able to read and understand it. With respect to driver responses to VMS information, on average, 13% of drivers reported changing route (ranging between 0% and 31%). These self-reported results were supported by the monitoring of traffic flows on the VMS routes and expected diversion routes. On average 11% of traffic passing a VMS was shown to have diverted (based on monitoring conducted in 13 corridors across London, Piraeus, Southampton and Turin). By contrast, only 1% of drivers were found to have switched from car to park and ride in Bristol when VMS showed comparative journey times. Thus VMS must be viewed only as a complementary measure in the development of successful park and ride schemes. With respect to the impact on network journey times, it was only possible to measure changes in journey times along VMS routes in one city (Piraues, Greece). On street measurement of six routes indicated a 16% reduction in travel time on average (ranging between 11% and 23%), suggesting potentially significant network efficiency gains through the use of VMS. No empirical evidence was available on safety or environmental impacts.

VMS systems were employed in Gothenburg, Sweden, to divert general traffic away from main public transport corridors[3]. The objectives here were to improve journey times for buses in heavily congested conditions in Gothenburg. The systems were evaluated using simulation modelling only. In Gothenburg, VMS were estimated to re-route up to 200 vehicles an hour away from the public transport corridor, contributing to an estimated 21% reduction in delay.

16.3.8 Methodologies and evidence gaps

1. UTC systems and emissions reductions: There is limited evidence on whether UTC systems can be optimised to reduce emissions as well as minimise delay across networks. The studies reported here mainly rely on simulation modelling rather than field measurement. It would be beneficial to conduct field trials which monitor air pollution levels over a period of time with and without emissions reduction algorithms.

2. Bus priority at traffic signals: The studies reviewed here have tended to report simple before and after bus journey times. Potential confounding factors (such as network wide changes in traffic conditions) have not been controlled for. However, the commonality in results from a wide range of cities gives confidence that such measures can be expected to improve journey times for public transport. A methodological improvement would be to use control sites (with no priority at signals) and to conduct appropriate statistical tests to identify whether the treated sites show significant improvements when set against the control sites. This also applies to the limited number of simple studies reviewed for enforcement of signals and bus lanes, and the removal of traffic signals.

3. Bicycle priority at traffic signals: Techniques to provide priority to bicycles at traffic signals are not widely used and this is reflected in a relatively weak evidence base. Further research on the specific management of bicycle traffic using traffic signal control is warranted.

4. VMS signs in urban areas: The review of field trials conducted in European cities is now over ten years old (and reports on trials conducted in the late 1990s). This study also relied on limited field data on how traffic volumes alter on VMS routes and diversion routes. No data was provided on environmental or safety impacts and this represents an evidence gap. Up to date field trials would be beneficial to identify the role of VMS in urban traffic management given recent advances in mobile technologies (with traveller information applications), and flexible, shared transport systems.

16.4 Lessons for Successful Deployment of this measure

16.4.1 UTC systems

Transferability: There are no systematic reasons to suppose that UTC systems, which are now widely used, will not be effective in other urban areas.

Drivers / Barriers: The implementation of UTC is often motivated by a need to improve traffic flow as congestion increases in urban areas i.e. They increase the capacity of space constrained networks in central areas, often to accommodate travel by private car. Care therefore needs to be taken that UTC systems are not designed to prioritise the movement of private cars at the expense of the more general objective to accommodate the movement of people through cities. In this respect, it has been demonstrated that UTC systems can be tuned to prioritise other modes at junctions.

Complementarity: In Aalborg, the development of a UTC was in part motivated by wider planning policies to regenerate a central area which saw the reduction of a four lane city centre road to a two lane road with consequent transfer of traffic to a nearby inner ring road. The UTC was able to increase capacity of junctions along the inner ring road to cope with the additional traffic. Hence UTC can be effectively used as part of a sustainable urban mobility policy in combination with road capacity reduction measures.

Durability: As UTC systems increase network capacity for private vehicles, it is likely that initial efficiency gains will tend to be eroded over time if traffic levels continue to increase. This emphasises the importance of using UTC in combination with ongoing policies to encourage the use of non-car modes in densely populated urban areas.

16.4.2 Removing traffic signal control

Transferability: The limited evidence on removing traffic signal control reviewed here indicates that this can be an effective means of improving junction efficiency for all users. However, this is likely to be highly context specific and further research is required to identify under what circumstances such measures are likely to be effective. Related interventions are considered in further detail in measure review 22.

Drivers and barriers: Strong public support was an important factor in the delivery of the trial and later permanent removal of signals in Portishead, UK. Conversely, a lack of public support, or a perception that removing signals will reduce safety (particularly for pedestrians, as demonstrated in Bristol), may limit the appetite amongst planners to implement a longer term strategy of signal removal.

16.4.3 Selective vehicle priority at traffic signals and enforcement

Transferability: The review of bus priority at traffic signals around the world confirms that such measures are likely to be effective in most contexts. Similarly, although the evidence base is less comprehensive, measures to increase priority to bicycles at traffic signals can also be expected to improve conditions for cycling.

Drivers and barriers: However, the extent to which bus or bicycle journey times are improved may be constrained by overarching policy frameworks for traffic control which set limits on the extent to which traffic signals are allowed to favour public transport or bicycles over general traffic. Systems of priority are most effective where networks are not already congested. In heavily congested conditions, it may not be possible to provide selective priority at signals as this will worsen the situation for all road users[3].

Complementarity: Bus or cycle lanes on approaches to traffic signals are required for priority measures at traffic signals to be effective. Absence of dedicated lanes will mean that buses or bicycles become delayed in general traffic queues, significantly limiting the extent to which priority at signals can have an impact on overall journey times. Automated enforcement of bus priority measures can be effective as long as cameras are highly visible and penalty notices are efficiently served to maintain credibility amongst drivers.

16.4.4 Variable Message Signs in urban areas

Transferability / Upscaling: The European field trials reviewed by Chatterjee and McDonald indicated that VMS systems are more likely to be effective if several signs are installed across a network. Single signs are less likely to be noticed and hence have little influence over drivers' route choice.

Drivers and Barriers: The success of VMS systems in alleviating congestion on specific routes is clearly dependent on the availability of capacity on alternative routes. Attempts to divert drivers through VMS will not be effective in heavily congested networks. Signs also need to be positioned sufficiently upstream of 'major decision points' in the network[2].

Complementarity: VMS systems are reliant on good real time data on traffic flows across a network in order to reliably estimate journey times on competing routes. Thus complementary traffic monitoring systems are required. VMS systems may themselves be used as a complementary measure to other interventions such as park and ride (displaying comparative journey times for example). In such circumstances, VMS can be expected to be effective in raising the profile of the park and ride, but are unlikely to deliver a significant modal shift in their own right.

Durability: Signs should be shown to be updated regularly to give drivers confidence in the reliability of information.

16.5 Additional benefits

As well as the evidence of economic and financial benefits of interventions discussed above, there are a number of additional benefits that are claimed for these policies:

- *Reducing traffic in city centres:* By improving capacity via UTC in some areas, it is possible to reduce capacity in others, providing support for other measures aimed at reducing traffic in city centres.
- *Road safety:* Enforcement cameras at signalised junctions have been demonstrated to reduce collisions and injuries, and dedicated phases for bicycle traffic at signalized junctions to reduce conflicting movements, making the environment safer for cyclists.
- *Encouragement for alternatives:* VMS can be a useful profile raising measure when used in conjunction with other measures such as park and ride.

16.6 Summary

- UTC systems can certainly be expected to improve network efficiency in terms of reducing delays to vehicles. However, there is limited evidence on the extent to which UTC algorithms can be optimised to reduce emissions. The estimated 1.5% fuel reduction reported here relied on simulation modelling rather than on field observations.

- Further research is also required to identify under what circumstances the removal of traffic signals is likely to improve junction efficiency and perceived safety for all road users.

- Where UTC systems and traffic signal controls are used to provide selective priority to public transport or bicycles, they can be expected to contribute to significant journey time savings (of for example between 3 and 11 seconds per bus per junction), without compromising journey times for other road users. They are most effective in uncongested conditions and must be deployed in conjunction with priority lanes on approaches to signalised junctions.

- Providing dedicated green phases for cycle traffic at signalised junctions has been shown to reduce conflicting movements, making the environment safer for cyclists.

- Systems that automatically monitor bus lanes and signalised junctions have been shown to reduce infringements, improve journey times and reduce collision rates at junctions.

- The success of VMS systems is typically measured in terms of the extent to which they encourage drivers to divert to less congested routes (or modes). Where several, well positioned signs are installed, VMS systems can be expected to divert around 11% of traffic (though this estimate is based on monitoring conducted in the later 1990s along 13 corridors in London, Piraeus, Southampton and Turin). They are unlikely to be effective in heavily congested networks and should be seen as a supplementary, profile raising measure when used in conjunction with park and ride. Updated field trials would be beneficial to identify the role of VMS in urban traffic management given recent advances in mobile technologies (with traveller information applications), and flexible, shared transport systems.

16.7 References for this Review

1. Gardner, K., D'Souza, C., Hounsell, N., Shrestha, B. (2009). Review of bus priority at traffic signals around the world. Brussels: UITP Working Group [online] Available from https://www.tfl.gov.uk/cdn/static/cms/documents/interaction-of-buses-and-signals-at-road-crossings.pdf [Accessed 21st April 2015].

2. Chatterjee, K. and McDonald, M. (2004). Effectiveness of variable message signs to disseminate dynamic traffic information: Evidence from field trials in European cities. Transport Reviews. 24(5), 559-585.

3. Transport Research Laboratory and Transportation Research Group (2000). INtegration of traffic COntrol with other MEsures. Final Report. Brussels: European Commission. [online] Available from http://www.transport-research.info/Upload/Documents/200310/income.pdf [Accessed 21st April 2015].

4. Stevanovic, A., Stevanovic, J., Zhang, K., Batterman, S. (2009). Optimizing traffic control to reduce fuel consumption and vehicular emissions. Integrated approach with VISSIM, CMEM, and VISGAOST. Transportation Research Record, 2128, 105-113.

5. Mogensen, J. (2013). Congestion monitoring using telematics in Aalborg. Brussels: European Commission. [online] Available from http://www.civitas.eu/sites/default/files/evaluation_congestion_monitoring_using_telematics.pdf [Accessed 21st April 2015].

6. Stevens, A. (2004) The application and limitations of cost-benefit assessment for intelligent transport systems. Research in Transportation Economics, 8, p.91-111.

7. Perret, K. and Stevens, A. (1996) Review of the potential benefits of road transport telematics. Crowthorne: Transport Research Laboratory.

8. Hill, R., Maxwell, A., Bretherton, D. (2001). Real time passenger information and bus priority system in Cardiff. Bus priority trial. Proceedings of the AET European Transport Conference. 10th-12th September, Homerton College, Cambridge, UK. [online] Available from http://abstracts.aetransport.org/paper/download/id/1257 [Accessed 21st April 2015].

9. Hounsell, N.B., McLeod, F.N., Bretherton, R.D. and Bowen, G.T. (1996). PROMPT: Field Trial and Simulation Results of Bus Priority in SCOOT. 8th International Conference on Road Traffic Monitoring and Control, Conference Publication No. 422, IEE, London, 23-25 April 1996, 95-99.

10. Zanin, V., De Chiara, G., Rossi, D. (2013a). Illegal on street parking reduction. Brussels: European Commission. [online] Available from http://www.civitas.eu/sites/default/files/mimosa_bol_8_2_mrt_pointer-f.pdf [Accessed 21st April 2015].

11. Ryding, H. (2007) Creen waves for cyclists in Copenhagen: Best practice guidelines. [Publisher unknown].

12. Knight, P., Bedingfield, J., Gould, E. (2004) Traffic management techniques for cyclists: Final report. Crowthorne: Transport Research Laboratory.

13. Wolfe, M., J. Fischer, et al. (2006). Bike scramble signal at North Interstate and Oregon. Portland: Portland State University.

14. Weighland, L. (2008) A review of literature: Intersection treatments to improve bicycle access and safety. [online] Available from https://www.pdx.edu/ibpi/sites/www.pdx.edu.ibpi/files/Multi-Modal%20Intersection%20Design.pdf [Accessed 17th July 2015]

15. Korve, M. and Niemeier, D. (2002) Benefit-cost analysis of added bicycle phase at existing signalized intersection. Journal of Transportation Engineering, 128(1): p.40-48

16. Harms, H.J. (2008) Bicycle Friendly Traffic - Evaluation Research [Publisher unknown]

17. Transport for London (2013) Further safety improvements at Box roundabout: Response to consultation [online] Available from https://consultations.tfl.gov.uk/betterjunctions/bow_roundabout/user_uploads/further-safety-improvements-at-bow-roundabout-consultation-report.pdf [Accessed 17th July 2015]

18. Zanin, V., De Chiara, G., Rossi, D. (2013b). Automatic enforcement of traffic lights. Brussels: European Commission. [online] Available from http://www.civitas.eu/sites/default/files/mimosa_bol_8_5_mrt_pointer-f.pdf [Accessed 21st April 2015].

19. Firth, K. (2011). Removing traffic engineering control – the awkward truth? Traffic Engineering and Control. 52(2), 73-79.

Author information for the Evidence Measure Reviews

No.1	Electric Battery and Fuel Cell Vehicles	Hüging, H[1,a]	hanna.hueging@wupperinst.org
No.2	Cleaner Vehicles	Rudolph, F[1,a]	frederic.rudolph@wupperinst.org
No.3	Urban Freight	Ricci, M[2,b]	Miriam.Ricci@uwe.ac.uk
No.4	Access restrictions	Melia, S[2,b]	Steve.Melia@uwe.ac.uk
No.5	Roadspace reallocation	Clark, B[2,b]	Ben4.Clark@uwe.ac.uk
No.6	Environmental zones	Calvert, T[2,b]	Thomas2.Calvert@uwe.ac.uk
No.7	Congestion charges	Mingardo, G. & Streng, M [3,c]	mingardo@ese.eur.nl
No.8	Parking	Mingardo, G. & Streng, M [3,c]	mingardo@ese.eur.nl
No.9	Site-based travel plans	Bartle, C[2,b]	Caroline.Bartle@uwe.ac.uk
No.10	Personalised travel planning	Bartle, C[2,b]	Caroline.Bartle@uwe.ac.uk
No.11	Marketing and rewarding	Rudolph, F[1,a]	frederic.rudolph@wupperinst.org
No.12	Public transport enhancements	Shergold, I[2,b]	Ian2.shergold@uwe.ac.uk
No.13	New public transport systems	Clark, B[2,b]	Ben4.Clark@uwe.ac.uk
No.14	Integration of modes	Calvert, T[2,b]	Thomas2.Calvert@uwe.ac.uk
No.15	e-ticketing	Shergold, I[2,b]	Ian2.shergold@uwe.ac.uk
No.16	Traffic management	Clark, B[2,b]	Ben4.Clark@uwe.ac.uk
No.17	Travel information	Calvert, T[2,b]	Thomas2.Calvert@uwe.ac.uk
No.18	New models of car use	Calvert, T. & Chatterjee, K [2,b]	Thomas2.Calvert@uwe.ac.uk
No.19	Walking	Jain, J[2,b]	Juliet.Jain@uwe.ac.uk
No.20	Cycling	Parkin, J[2,b]	John.Parkin@uwe.ac.uk
No.21	Bike sharing	Ricci, M[2,b]	Miriam.Ricci@uwe.ac.uk
No.22	Inclusive urban design	Melia, S[2,b]	Steve.Melia@uwe.ac.uk

1	Wuppertal Institut für Klima, Umwelt und Energie GmbH	a	Wuppertal Institut, Döppersberg 19 42103 Wuppertal. Germany.
2	University of the West of England: Bristol	b	Centre for Transport and Society, University of the West of England, Frenchay Campus, Coldharbour Lane, Bristol BS16 1QY. UK
3	RHV Erasmus University Rotterdam	c	RHV BV, TAV Martijn Streng, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands