Framework for transport-related technical and engineering advice and research

Lot 2: Road Transport Package Order 687(4/45/12) - Algorithm Improvement

Prepared for: Highways England
Project Ref: 11113881

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Algorithm Improvement

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Contents amendment record

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1 Introduction

1.1 Background

Highways England currently use MIDAS (Motorway Incident Detection and Automatic Signalling) to set automatic signals on the motorway network and use a queue protection (QP) algorithm (High Occupancy (HIOCC)) and a congestion management (CM) algorithm. There have been concerns that the QP algorithm is causing signals to be set without any apparent incident which will cause additional delay and also reduce driver confidence in the system, which will over time reduce the effectiveness of the system.

The QP algorithm (HIOCC) was developed in the 1970s, and the CM algorithm in the 1990s. Both have been in use and relatively unchanged since then. An enhanced version of HIOCC was rolled out onto the network from 2003 onwards that improved reliability of the system; however the basic algorithm has remained the same.

QP signals are set in response to slow-moving traffic, and so speed should be the basic parameter to use. However, in the early days of detector technology, speed data was unreliable (it requires two adjacent functioning loops), so occupancy was used instead (as that only requires one functioning loop of a pair). The HIOCC2 enhancement uses speed as its first priority, only reverting to occupancy when speed data is unavailable. This improves predictability of the signal settings, as occupancy alerts are typically generated by long vehicles, not necessarily travelling particularly slowly.

1.2 Purpose

The purpose of this project is to carry out a desk-based evaluation exercise, assessing the existing algorithms, reviewing algorithms used elsewhere in the world, and providing recommendations for any next steps regarding any changes that could be made to enhance the reliability, appropriateness and effectiveness of automatic signalling in the future.

The objectives of the project reflect one of the strategic objectives of Highways England in terms of improved network operation – “keeping the traffic moving and better informing our customers”. There is one headline objective and five primary objectives, which are outlined in Table 1 and Table 2 respectively.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Primary Objectives</th>
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<tbody>
<tr>
<td>P1</td>
<td>To review queue protection, incident detection and congestion management algorithms used worldwide on Motorways/Highways</td>
</tr>
<tr>
<td>P2</td>
<td>Include a summary of Customer panel historic work</td>
</tr>
</tbody>
</table>
Consider which algorithms are most suited to our forthcoming Expressways, which shall be a combination of Motorway and APTR (All-Purpose Trunk Road) class roads

Highlight any particular algorithms that have been developed to improve air quality of the surrounding network

Horizon scan for future developments alongside the historical summary; this may include vehicle to vehicle systems, CHARM (Common Highways Agency Rijkswaterstaat Model), Internet Protocol connectivity, or other pilot or theoretical studies

1.3 Methodology

The project has been conducted as five work packages through which the headline objective (H1) and the five primary objectives (P1 – P5) are delivered. The work packages are outlined in Table 3.

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<td>Review algorithms used worldwide</td>
</tr>
<tr>
<td>WP2000</td>
<td>Review current algorithms used by Highways England</td>
</tr>
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<td>WP3000</td>
<td>Consider suitable algorithms for forthcoming Expressways</td>
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<tr>
<td>WP4000</td>
<td>Investigate air quality algorithms and horizon scan future developments</td>
</tr>
<tr>
<td>WP5000</td>
<td>Produce summary report, including recommendations</td>
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This report is the summary report detailed in WP5000.
2 WP1000: Review algorithms used worldwide

2.1 Purpose
To review QP, incident and CM algorithms used worldwide on motorways, highways or freeways.

2.2 Methodology
In order to review algorithms used worldwide, a desk-based literature review was carried out and worldwide contacts from other research organisations and national road authorities were contacted to provide the following information:

- What system(s) (if any) do you currently use?
- How long have you been using the system(s) for?
- Are the schemes you use manually operated, set to a fixed time plan or traffic-responsive in some way?
- What assessment(s) (if any) have you carried out on the scheme(s)?

The information collected from worldwide schemes was then used to populate a comparison table detailing the results.

2.3 Results - literature review
A literature review was undertaken of recent research from 2000 onwards, but also included earlier research that is relevant to this particular study, on automatic incident detection algorithms (AID). Much of this research focuses on the development of new incident detection algorithms. Research has also been conducted on the modification of existing algorithms and on the evaluation or comparison of existing AID.

2.3.1 Research into existing incident detection algorithms in use on the road
Research includes the enhancement or modification of existing automatic incident detection (AID) algorithms to improve performance and comparative evaluations of AID currently in use. A summary of these research findings can be found in Appendix A.

Research findings were used to enhance the existing calibrated incident detection algorithms for an expressway in Singapore (Chin Long & Fan, 2005)\(^1\). A study undertaken by (Brydia et al., 2005)\(^12\) proposed a minimal modification to the incident detection algorithm that decreases the false alarm rate and increases the detection rate.

A comparative evaluation of the performance of selected incident detection algorithms was undertaken in terms of statistical performance measures: false alarm rate, detection rate and mean-time to detect (Deniz et al., 2012)\(^2\). A comparison of an earlier Dutch algorithm with several other algorithms was undertaken to investigate how the current loop detector data of traffic speed and flow can be used to detect incidents (Knibbe et al., 2006)\(^43\). An assessment of the strengths and limitations of available sensor technologies and their corresponding algorithms was undertaken by (Parkany and Xie, 2005)\(^59\). A comparison and analysis tool was developed for automatic incident detection system using real-time traffic video data (Browne et al., 2005)\(^11\). This test bed was used to calibrate and analyse the performance of three AID algorithms: California Algorithm 8, the McMaster algorithm, and the genetic adaptive incident detection algorithm. Research was undertaken by
(Martin et al., 2001)\textsuperscript{52} to examine a range of incident detection technologies to determine combinations of approaches for a Traffic Management System. Earlier research by (Dia et al., 1996)\textsuperscript{24} evaluated the statistical performance of the incident detection algorithm implemented at that time on Melbourne’s freeways. Results showed a substantial improvement in incident detection performance using the Artificial Neural Networks model over the ARRB/VicRoads model.

### 2.3.2 Research into algorithms for congestion management

During the literature search, a number of research articles were identified related to specific algorithms for CM, including ramp metering. A summary is provided for each of these research articles in Appendix B.

### 2.3.3 Research into new automatic incident detection algorithms

A large amount of research has been undertaken on new automatic incident detection algorithms. Very few of these algorithms of have been deployed operationally on the road. A summary of the research findings for each of these research findings can be found in Appendix C.

Research has been undertaken into the development of Artificial Intelligence Algorithms for automatic incident detection. A hybrid algorithm developed by (Lu et al., 2011)\textsuperscript{50} combined the partial least squares method and an artificial neural network to automatically detect a traffic incident. Results showed that this hybrid model was a promising alternative method of incident detection compared with the usual neural network or partial least square methods. A method of improving the accuracy of detecting incidents on expressways was described by (Yao et al., 2013)\textsuperscript{85}. This method employed a tabu search algorithm (a metaheuristic algorithm) to optimize the Support Vector Machine parameters which can improve prediction accuracy. This method, which was evaluated using real traffic data, can outperform Artificial Neural Networks in freeway incident detection.

A wavelet-based novel automatic detection algorithm with varying threshold parameters for freeways was proposed by (Young-Seon et al., 2011)\textsuperscript{86}. Using both simulated and real time traffic data, the performance of this algorithm was compared with existing algorithms, such as the California and Minnesota algorithm. Results showed that this wavelet-based algorithm consistently outperformed the other algorithms. A new technique for incident detection using a hybrid neuro-fuzzy system was proposed by (Sanyal & Sharma, 2007)\textsuperscript{65}. This system was shown to be highly adaptable and had high potential for freeway incident detection. An incident detection model consisting of an artificial neural network and a neuro-fuzzy algorithm was proposed by (Ryu et al., 2007)\textsuperscript{65}. This hybrid model showed a high detection rate of 83% and a false alarm rate of 0.017%.

Three neural network models (multi-layer feed-forward neural network, basic probabilistic neural network and constructive probabilistic neural network) were developed and tested on a freeway for their adaptability (Srivivasan et al., 2004)\textsuperscript{70}. Results showed that the constructive probabilistic neural network model had the greatest potential for use in an operational environment on a freeway. To overcome the computational complexity of neural network algorithms increasing exponentially with the size of the network, a hybrid feature extraction algorithm and neural network architecture was developed for automatic detection of traffic incidents (Wu & Adeli, 2001)\textsuperscript{84}. An article by (Samant & Adeli, 2001)\textsuperscript{64} described how the performance of a fuzzy neural network algorithm for freeway incident detection could be improved through pre-processing of data using a wavelet-based feature extraction model to de-noise the traffic data.

Research has also been conducted into the development of algorithm fusion methods for automatic incident detection. The development of an algorithm fusion method using real incident data collected from an expressway was described by (Chin Long & Fan, 2006) (a)\textsuperscript{16}. These fused
algorithms outperformed existing algorithms, with significantly lower false alarm rates. An alternative algorithm fusion method was proposed by (Chin Long & Fan, 2011)\textsuperscript{15}. These algorithms were evaluated on freeways in Melbourne to demonstrate its transferability potential in detecting incidents. These algorithms gave a high detection rate of 80% with false alarm levels below 0.2% and mean-time to detect values less than 150 seconds. The development of a Dempster - Shafer (D-S) theory data fusion based automatic incident detection algorithm for expressways was proposed by (Weng et al., 2011)\textsuperscript{82}. This algorithm was validated using fixed detector data, floating car data and event data from a Beijing expressway. Results of this validation showed that the D-S theory algorithm outperformed classical algorithms at false alarm rate.

Recent research has been undertaken into the evaluation of recently developed automatic incident detection algorithms (Dynamic Time Warping and Support Vector Machine) in recognising traffic patterns when incidents occur during stop and go conditions (Notamed & Machemehl, 2014)\textsuperscript{55}. Research has also been conducted into the development of an algorithm which combines the Californian algorithm and the filter algorithm (Tan & Lu, 2011)\textsuperscript{73}. Results of simulation studies showed that the combined algorithm can enhance detection rates and reduce false alarm rates. An incident detection algorithm based on two-dimensional integration and analysing car and traffic event data was proposed by (Zhao et al., 2010)\textsuperscript{91}. This algorithm was verified with floating car data and traffic incident data collected from an expressway. Results showed an 87% detection rate and a 1.86% false alarm rate. (Wang et al., 2008)\textsuperscript{81} described the development of freeway incident detection models based on partial least squares regression. Detection performance was evaluated using the common criteria of detection rate, false alarm rate and mean-time to detection. Results of experiments using simulated traffic data from an expressway and real time data from a freeway showed the potential application of automatic incident detection in the real world.

An arterial road incident detection algorithm using Bayesian networks was proposed by (Zhang & Taylor, 2006)\textsuperscript{89}. In this model, Bayesian networks quantitatively modelled the dependencies between incidents and traffic parameters. Simulations performed on a number of different arterial road incidents evaluated the performance of the algorithm, with a high detection rate of 88% and a low false alarm rate (0.62%). An automatic incident detection algorithm that is weather-responsive was proposed by (Li et al., 2014)\textsuperscript{48}. For the proposed algorithm, a detection threshold was set for incident detection under rain/no rain conditions. Traffic, accident and rainfall data were collected on a road network to calibrate and validate the proposed algorithm.

2.4 Results - responses from worldwide contacts

A total of 84 people from other research organisations and national road authorities were contacted for information, representing the following 22 countries: Australia, Austria, Belgium, Bulgaria, China, Czech Republic, Denmark, Estonia, Germany, Hungary, Ireland, France, Finland, Italy, Luxembourg, Norway, Slovenia, Spain, Sweden, Switzerland, The Netherlands and the United States. A total of 22 responses were received from contacts, representing the following 14 countries: Austria, Australia, Belgium, Denmark, Estonia, Finland, Hungary, Ireland, Norway, Slovenia, Sweden, Switzerland, the Netherlands and the United States. A summary of the responses received is provided in Table 4.
### Table 4: Responses from worldwide contacts

<table>
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<tr>
<th>Country</th>
<th>Representing organisation(s)</th>
<th>Original response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>ASFINAG</td>
<td>Currently in planning phase of re-tendering traffic management software, including algorithms for traffic control schemes. Software developed by Siemens and Heusch Boeselfeld in 2005. Special algorithms used. Some tunnels equipped with automatic incident detection system. System used since 2005, fully automatic, lots of analysis carried out.</td>
</tr>
<tr>
<td>Australia</td>
<td>VicRoads</td>
<td>Queue protection: we currently do not have any queue protection algorithms but are in the process of developing one over the next year. Incident detection - our current incident detection system is not satisfactory and we are also investigating alternative incident detection system. In the meantime we have incident response services patrolling our metropolitan freeways to complement the services delivered by our Traffic Management Centre. VicRoads would appreciate if you could also share with us in your research what incident detection system others are using and has worked well. Congestion management - This is the area where VicRoads have made significant inroads in the way we manage our freeway. We have implemented a dynamic coordinated ramp metering system called HERO on our M1 freeway (approx. 75km) and M80 (approx. 40km) and is in the process of rolling out to a major Gateway motorway from the Airport to the CBD.</td>
</tr>
<tr>
<td>Belgium</td>
<td>Walloon Road Authority and Verkeerscentrum</td>
<td>In the middle of a project to upgrade traffic system to jump into ITS revolution. On motorways, lane-control signs are installed connected with induction loops, algorithm used to provide queue tail protection. System installed in 2003, automatic queue tail protection in operation since 2008. Speed limits normally operated automatically – are traffic-responsive. Assessment survey carried out and provided.</td>
</tr>
<tr>
<td>Denmark</td>
<td>Danish Road Directorate</td>
<td>Own system developed in 2010 to handle ITS-systems on roadside called GUI/SLM.</td>
</tr>
<tr>
<td>Estonia</td>
<td>Ministry of Economy &amp; Transport</td>
<td>Dynamic traffic management systems (MIDAS, HIOCC) are not applied on national roads.</td>
</tr>
<tr>
<td>Finland</td>
<td>FTA</td>
<td>Not currently using any automatic detection for incident of congestion detection widely. Do not have traffic related algorithms largely in use. Have dynamic traffic management systems on the whole E18 road plus critical sections of main roads. Typical systems include VMS signs, cameras, road weather stations and traffic data collection points. First systems made almost 20 years ago. Systems controlled by using traffic and weather data. Guidelines document of traffic management control policies provided with email (in Finnish).</td>
</tr>
<tr>
<td>Hungary</td>
<td>Hungarian Transport administration</td>
<td>Várható Utazási idők (VUK) – Expected Travel Time system is currently used and VMS also used. Schemes used since</td>
</tr>
<tr>
<td>Country</td>
<td>Representing organisation(s)</td>
<td>Original response</td>
</tr>
<tr>
<td>------------------</td>
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</tr>
<tr>
<td>Ireland</td>
<td>Transport Infrastructure Ireland (TII)</td>
<td>March 2009 and are automatic / traffic-responsive. Incident warning system also used since 2008 and are automatic with manually activated VMS. ATMS (Advanced Traffic Management System) provided by IBI Group. AID algorithms used (McMaster, APID, MSTQ). The Traffic Monitoring Units do not run any local detection algorithms such as HIOCC or VMOD. ATMS used since 2004, the AID capability and roadside detection equipment was deployed in 2013. Assessment was carried out after installation until the DR and FAR were at an acceptable level for the live system to be deployed.</td>
</tr>
<tr>
<td>Norway</td>
<td>Norwegian Public Roads Administration</td>
<td>No Motorway Control Systems have been deployed or are planned. Have Automatic Incident Detection in some tunnels but not a full-scale MCS. Limited number of motorways, no motorway control systems. Little focus on improving traffic flow. Some stand-alone ramp metering systems on 2-lane highways (used over last 20 years) with locally designed algorithms, some manual and some automatic. Incident detection systems used for traffic safety – CCATS used to detect stand still queue and ANPR systems from AADI used at both sides of tunnels.</td>
</tr>
<tr>
<td>Slovenia</td>
<td>DARS</td>
<td>TMS from Traffic Design (Q Free) - Motorway Incident Detection and Automatic Signalling used in some sections. System has been in use for 10 years and its operation is both manual and automatic. Schemes are regularly optimised.</td>
</tr>
<tr>
<td>Sweden</td>
<td>Trafikverket</td>
<td>MTM-2 system used for queue warning (from Holland), in use for 20 years mainly around Stockholm. Currently have in-house development PLC-based queue-warning system in Gothenburg. Starting development of a new central system for controlling VMS-lane signs since MTM-2 will be discontinued by RWS, scheduled for release 2019. Automatic queue warnings.</td>
</tr>
<tr>
<td>Switzerland</td>
<td>ASTRA</td>
<td>Since 2008 FEDRO is responsible for the traffic management systems on motorways. In final stage to define a new system (SA-CH). For line control systems use state of the art algorithms, for ramp metering use a Switzerland-specific algorithm (Swiss Norm: SN640807) or ALINEA. Use the technical bulletin to equip traffic-management systems and control centres (&quot;Merkblatt zur Ausstattung von Rechnerzentralen [MARZ99]&quot;) of the Federal Highway Research Institute (BASt) in Germany.</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>Rijkswaterstaat and TrafficQuest</td>
<td>The MTM system (developed by Rijkswaterstaat) in use since 1980. The AID algorithm within MTM is traffic-responsive and operates automatically. VMS used, operating autonomously most of the time, in use since early 1990s. Hard shoulders operated using an automatic tool (&quot;BOSS-online&quot;, from about 2010) and CBA system in use which is half-automated. Several of these systems will be replaced within a few years by a DYNAC-based ATMS that Rijkswaterstaat and Highways England have jointly procured. Lots of assessment carried out on all kinds of traffic management measures.</td>
</tr>
</tbody>
</table>
2.4.1 Comparison table

The comparison table shown in Table 5 includes details of information obtained from the responses given by different countries. This includes the system intelligence used, i.e. whether it is an automatic algorithm or is manual, detection method(s) used (input), how the information is passed to the driver (output), how the performance of the system is assessed and any available information regarding the benefits/drawbacks of the system.
<table>
<thead>
<tr>
<th>Country</th>
<th>System intelligence used (manual or algorithm)</th>
<th>Detection methods (input)</th>
<th>How information is passed to drivers (output)</th>
<th>Performance assessment of system</th>
<th>Benefits/drawbacks of system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>Special algorithms are currently used</td>
<td>System runs fully automatically - reacts on traffic parameters like traffic volume, speed, occupancy, and other parameters - rain intensity, water film, visibility, etc. Manual intervention is possible at all times</td>
<td>Automatic signalling for queue protection, ban on HGV’s overtaking, variable speed limits, adverse weather conditions, air pollution and noise reduction</td>
<td>Several assessments have been made over the last few years to prove the effectiveness of the roadside equipment</td>
<td>None provided</td>
</tr>
<tr>
<td>Australia</td>
<td>Our current incident detection system is not deemed satisfactory – are currently investigating an alternative one</td>
<td>HERO is a dynamic system that switches on and off based on traffic conditions and the control logic is traffic response using speed, volume and primarily occupancy for control</td>
<td>Freeway ramp metering using traffic signals to control entry ramp traffic</td>
<td>Before and after evaluation of the HERO system; results are promising with throughput and speed improved in excess of 19% and crash rates reduced by over 24%</td>
<td>None provided</td>
</tr>
<tr>
<td>Belgium</td>
<td>Flanders Road Agency</td>
<td>Automatic algorithms are traffic-responsive (reactive) and are based on a combination of speed and occupancy</td>
<td>Connected with induction loops</td>
<td>Automatic lane control signals provide queue tail protection</td>
<td>None provided</td>
</tr>
<tr>
<td>Belgium</td>
<td>Wallonia Roads Department</td>
<td>Cameras</td>
<td>Variable Message Signs (VMS)</td>
<td></td>
<td>None provided</td>
</tr>
<tr>
<td>Country</td>
<td>System intelligence used (manual or algorithm)</td>
<td>Detection methods (input)</td>
<td>How information is passed to drivers (output)</td>
<td>Performance assessment of system</td>
<td>Benefits/drawbacks of system</td>
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<tr>
<td>Denmark</td>
<td>Algorithms to calculate travel time, queue warning, speed harmonization, dynamic speed adaption</td>
<td>Detectors can be loops in the road, radar detectors, wind or road sensors, cameras, or other sensors</td>
<td>Variable message signs (both text and pictograms) and warning signals</td>
<td>The evaluation process of ITS involves regular monitoring of uptime and critical errors over the last 12 months</td>
<td>None provided</td>
</tr>
<tr>
<td>Estonia</td>
<td>Dynamic traffic management systems (e.g. MIDAS, HIOCC) are not used on national roads</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Finland</td>
<td>Traffic algorithms are not largely in use</td>
<td>Cameras in a few tunnels to detect stopped vehicles</td>
<td>Variable Message Signs – speed limit and traffic information</td>
<td>Performance assessment is being carried out all the time so that changes can be made to control policies if required</td>
<td>None provided</td>
</tr>
<tr>
<td>Hungary</td>
<td>A specific algorithm is used to send travel time information to VMS</td>
<td>Number plate cameras</td>
<td>Variable Message Sign (VMS) displaying travel times, speed limits, accident warnings, weather warnings, etc.</td>
<td>No information has been provided</td>
<td>None provided</td>
</tr>
<tr>
<td>Ireland</td>
<td>ATMS (Advanced Traffic Management System) runs AID algorithms on 20 second traffic data</td>
<td>ANPR cameras, Traffic Monitoring Units (inductive loops)</td>
<td>Variable Message Signs (VMS) displays traffic information (e.g. real time journey information, weather event information, safety campaigns, etc.)</td>
<td>After the scheme was installed, an extended performance test was carried out to review the Detection Rate, False Alarm Rate and to tune the AID algorithms</td>
<td>None provided</td>
</tr>
<tr>
<td>Country</td>
<td>System intelligence used (manual or algorithm)</td>
<td>Detection methods (input)</td>
<td>How information is passed to drivers (output)</td>
<td>Performance assessment of system</td>
<td>Benefits/drawbacks of system</td>
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</table>
| Norway  | queue detection, deployed in 2013
APID (All Purpose Incident Detection) - Incident detection
MSQT (Multiple Speed Threshold Queue) - Queue detection
The roadside Traffic Monitoring Units do not run any local detection algorithms like HIOCC | Video based systems like CCATS to detect stationary queues
Inductive loop based systems to detect queues and slow moving vehicles | VMS provides Active Traffic Management of Unplanned events and incidents | Once the DR and FAR were at an acceptable level to the MTCC Operators, the system was deployed to the live system | None provided |
| Slovenia | Stand-alone ramp metering systems algorithms are designed locally by supplier or by consultant | Video detection system | Variable Message Signs (VMS) to warn drivers about stationary queues
ANPR systems are used at both sides of tunnels | A regular optimization of schemes | None provided |
<p>| Sweden  | TMS - Motorway Incident Detection and Automatic Signalling from Traffic design (Q FREE) | Video detection system | Variable Message Signs (VMS) and Lane control signals | | The system has resulted in fewer accidents and a better traffic flow: <a href="https://www.swarco.com/en/References/INTERURBAN-TRAFFIC-MANAGEMENT/INTERURBAN-TRAFFIC-MANAGEMENT-Sweden,-Stockholm-Trafikverket-Region-Stockholm">https://www.swarco.com/en/References/INTERURBAN-TRAFFIC-MANAGEMENT/INTERURBAN-TRAFFIC-MANAGEMENT-Sweden,-Stockholm-Trafikverket-Region-Stockholm</a> |
|         | MTM-2 automatic queue warning system from the Netherlands, in use for 20 years | Falcon microwave detector mounted on gantries above each lane | Variable Message Signs (VMS) and Lane Matrix Signals | | |</p>
<table>
<thead>
<tr>
<th>Country</th>
<th>System intelligence used (manual or algorithm)</th>
<th>Detection methods (input)</th>
<th>How information is passed to drivers (output)</th>
<th>Performance assessment of system</th>
<th>Benefits/drawbacks of system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switzerland</td>
<td>Switzerland- specific algorithm (Swiss Norm:SN640907) or ALINEA for ramp metering</td>
<td>Tritech overhead - detectors (combination of three sensors in one detector, lane based) or inductive loops. Laser scanners are also used in some cases</td>
<td>Standard VMS displays information to drivers</td>
<td>A performance indicator is not used for detection rate or false alarm rate. Due to heterogeneous database, we do this project-based at the moment. In future, there should be a performance monitoring (for optimize the traffic management systems and speed up maintenance operations)</td>
<td>None provided</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>The Automatic Incident Detection algorithm (which is used for queue detection and protection) within the Motorway Management System is traffic-responsive and operates automatically: both queues being detected and approaching vehicles being warned through lower speed limits and flashers. For temporary use of the hard shoulder, an automated tool ‘BOSS-online’ is used to indicate whether a hard shoulder should be open or closed. This system is semi-automated – the operator must view all pictures from the cameras and manually -</td>
<td>Cameras are used to identify any broken down vehicles</td>
<td>Drivers are informed about travel times through Variable Message Signs (VMS), often two alternative routes being on display. This system operates autonomously most of the time (except from e.g. road works and major disruptions to the network, when traffic operators may override it)</td>
<td>Warning legends are displayed on lane signals. Netherlands have carried out a lot of evaluations (about 200 from 1990 until now) on all kinds of traffic management measures, such as queue detection and warning, ramp metering, variable message signs, peak hour lanes, incident management, speed control, etc. Most of these evaluations led to reports written in Dutch (we have been sent a presentation with a summary of these evaluations in Dutch)</td>
<td>None provided</td>
</tr>
<tr>
<td>Country</td>
<td>System intelligence used (manual or algorithm)</td>
<td>Detection methods (input)</td>
<td>How information is passed to drivers (output)</td>
<td>Performance assessment of system</td>
<td>Benefits/drawbacks of system</td>
</tr>
<tr>
<td>--------------------</td>
<td>------------------------------------------------------------------------------------------------------------------</td>
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<td>-----------------------------------------------</td>
<td>--------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>United States</td>
<td>None provided</td>
<td>None provided</td>
<td>None provided</td>
<td>None provided</td>
<td>None provided</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>HIOCC for queue protection Speed/flow for congestion management</td>
<td>Inductive loops and radar</td>
<td>Variable Message Signs (displays text and pictograms) Gantry mounted AMI signs for mandatory/advisory speed limits</td>
<td>Evaluation when system is first switched on. Regional assessments.</td>
<td>None provided</td>
</tr>
</tbody>
</table>
2.4.2 **Signal switch off**
No information has been provided.

2.4.3 **Component failure**
No information has been provided.

2.4.4 **Implementation of outputs**
From the responses given, the output of the algorithms is disseminated to road users via variable message signs (VMS). VMS can be used to display traffic information or speed limits. Traffic information includes warning messages and travel times. The information displayed on VMS can be text, graphics (pictograms) or a combination of both. Automatic lane control signalling is provided for QP.

2.4.5 **Speed limits**
In Denmark, mandatory speed limits are used to control traffic and Switzerland only use mandatory speed limits (i.e. systems with variable speed limits (VSL)); however, little information has been forthcoming so far from most other countries on their use of mandatory or advisory speed limits to control traffic.

2.4.6 **Instation or Outstation**
No information has been provided.
3 WP2000: Review algorithms used by Highways England

3.1 Purpose
The purpose of this work package is to review the QP, incident and CM algorithms currently used by Highways England to determine whether they could be improved and/or developed.

3.2 Methodology
Desk-based research was undertaken using the knowledge gained during WP1000 on worldwide experience to review the Highways England algorithms and to help identify possible improvements or enhancements. The summary of Customer Panel historic work provided by Highways England was reviewed and the knowledge gained through monitoring and assessing the algorithms over the years was also reviewed in order to identify areas where the algorithms might be underperforming.

3.3 Results
There are two algorithms that set speed restrictions on the Highways England network: the QP algorithm and the CM algorithm. A third algorithm (Ramp Metering) sets traffic light signals on slip roads, and will be mentioned briefly. However, this work package mainly concerns the operation of the main carriageway algorithms.

The QP and CM algorithms were both developed many years ago – the QP algorithm in the 1970s and the CM algorithm in the 1990s. The functionality of both has remained relatively unchanged since then. A few enhancements have been added to each, but the underlying algorithms are as originally designed.

The QP algorithm is a reactive algorithm: it sets signalling in response to slow-moving traffic. The CM algorithm is a proactive algorithm: it sets signals in response to high flows, to manage traffic and reduce the occurrences of flow breakdown.

The two algorithms run in parallel. Each is run using real-time traffic data obtained from detectors (originally loops, but more recently radar), and generates alerts whenever an event is detected. Each alert is processed and a requirement for a set of speed limits is set up for a bank of signals. Each signal then displays the most restrictive speed setting required, irrespective of the source of the alert. For a signal to display a less restrictive speed setting, or clear altogether, all of the alerts for a particular speed limit must clear.

Both algorithms were originally designed to be quick-response, and react quickly to changes in traffic conditions. The QP algorithm remains quick-response, but the CM algorithm is now more damped down. The CM algorithm gives greater weighting to the current average data than to the data from the latest minute, meaning that the signals do not often change.

The two algorithms have been running in parallel since 1998, and in general provide signalling that is consistent, coherent and appropriate to the traffic conditions. However, there are some issues with the operation of the algorithms, and these are discussed in the following sections.

3.4 Queue Protection
The basic principle is that the QP algorithm detects slow-moving traffic, and then sets speed limits upstream of the event in order to protect the back of the queue. 40mph signals are set close to the incident, then lead-in signals of 60mph further upstream. If gantries are close together, then one of
the 60mph lead-ins is reduced to 50mph to produce a smooth slowing of traffic approaching the queue.

The QP algorithm responds to slow-moving traffic. It would ideally be run using speed data. However, in the early days of traffic detectors, the loops were not reliable enough to provide speed data from all detectors. Loops are configured in pairs, and speed requires both loops of a pair to be working. If either loop fails, then speed data is lost. However, a single loop can still measure flow and occupancy. Occupancy is the time for which a vehicle is over a loop. This will depend on the vehicle speed, but also the vehicle length.

The threshold for triggering a QP alert is typically two seconds. This equates to a 4m long car travelling at 7mph, or a 15m HGV travelling at 25mph. Longer abnormal loads can trigger HIOCC at even higher speeds. This introduced some variability into the operation of HIOCC, as the speeds at which the signalling came on were partly dependent on the vehicle mix.

In 2002, HIOCC2 was developed to remove some of this variability. The principle of HIOCC2 was to use speed data where possible, and revert to occupancy only where speed was not available. Rather than rewrite the algorithms, HIOCC2 introduced a Watchdog. HIOCC alerts are still generated as previously, but if the vehicle that generated the alert was travelling faster than a predefined speed (typically 7mph), then the alert was suppressed by the Watchdog.

HIOCC2 required updated software to be installed in the outstations. This was done on a site-by-site basis initially, and a more concerted rollout of HIOCC2 followed later. Most outstations are now equipped for HIOCC2. Table 6 shows the current situation for each Regional Control Centre (RCC).

<table>
<thead>
<tr>
<th>RCC</th>
<th>Region</th>
<th>HIOCC2 status</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>North East</td>
<td>All complete except A1(M), 200 sites being done</td>
</tr>
<tr>
<td>20</td>
<td>North West</td>
<td>Fully compliant</td>
</tr>
<tr>
<td>30</td>
<td>East</td>
<td>Ten sites left to do</td>
</tr>
<tr>
<td>40</td>
<td>West Midlands</td>
<td>Fully operational</td>
</tr>
<tr>
<td>50</td>
<td>East Midlands</td>
<td>Fully operational</td>
</tr>
<tr>
<td>60</td>
<td>South West</td>
<td>All outstations have been done and site data is fully compliant</td>
</tr>
<tr>
<td>70</td>
<td>South East</td>
<td>Ten sites left to do</td>
</tr>
</tbody>
</table>

HIOCC and HIOCC2 are designed to be highly responsive systems, as they are setting safety-critical signalling. Therefore, signals come on very rapidly once an alert is generated – the typical time from alert to signals being set is 3 seconds. This very quick response increases the false alarm rate, as there is little cross-checking to validate the alerts. Other algorithms will perform sense-checks on the alerts, which will slow the speed of response, and will possibly result in some real incidents being discarded. Examples of checks that could be done for HIOCC are:

- Validate speed on adjacent lanes. For example, if the speeds in adjacent lanes are 70mph, then a reported slow speed is unlikely to be a real incident.
- Validate queues on two consecutive detectors. If two consecutive detectors register slow-moving traffic, then a queue has formed and needs to be protected. The drawback is that the initial queue will be unprotected for a few minutes.
Performance criteria can be quoted for QP, measuring Detection Rate, Speed of Detection, Clearance Time and False Alarm Rate. Care needs to be taken when comparing specific quoted values for each of these, as the definitions of each can vary. In particular, the False Alarm Rate can be measured in a number of different ways. It can be the proportion of alerts that are false, the proportion of incidents that are falsely reported, or the proportion of individual measurements that are false. Also, the performance criteria can refer to the detection of queues or the detection of individual slow-moving vehicles. However, a comparison of the ranges of quoted performance criteria for HIOCC and other algorithms can be made:

- Detection Rate. This is very high for HIOCC. Quoted values are over 90%, with 100% being claimed over some test periods. Quoted values for other systems are generally in the high 80s.
- Speed of Detection. HIOCC is very responsive in setting signals, with only a few seconds delay between detecting an alert and setting signals. Other systems have speeds of detection of between 2 and 3 minutes.
- False Alarm Rate. This is high for HIOCC. As stated above, the quoted values depend on the definition used, but as HIOCC is a quick response system with few validation checks, there are relatively frequent false alarms.
- Clearance Time. HIOCC is quick to clear once traffic starts running normally, with alerts typically clearing within 90 seconds. There have been issues with HIOCC not clearing when activated in lanes closed for roadworks, so HIOCC is now generally deactivated within roadworks areas.

For a relatively simple algorithm, HIOCC performs its function well. It is a rapid response system that is generally resilient to detector failures (i.e. lack of data from a particular lane or detector array). Each lane is treated as a separate entity, so if a lane sensor fails, queues will still be detected in other lanes at that location. If a whole detector array fails, queues will be detected at the next upstream sensor. Detectors are typically spaced at 500m intervals on the motorway network, meaning that a queue will reach the upstream detector within 90 seconds during congested periods.

One disadvantage of a rapid response system is that signals are set without any confirmation or verification of an alert. This can lead to inappropriate signalling. The signal rules for HIOCC are configurable, but in practice are not changed from the default settings. When a QP signal is set, it has to remain set for at least 4 minutes (the minimum on time). This is to prevent the signals switching rapidly on and off in stop-start driving conditions. A side effect is that if a false alert is generated, the signals have to remain set for 4 minutes. This can cause driver dissatisfaction, and can eventually lead to poorer compliance.

One major drawback to the way that HIOCC operates is that there is normally no audit trail to show what vehicle(s) generated an alert and caused the signals to be set. HIOCC runs off instantaneous occupancy (polled every 1/10 second), and generates an alert as soon as the occupancy threshold is exceeded. These alerts are generated within the outstations and transmitted back to the RCCs for processing into signal settings. The data for the vehicle generating the alert is held by the outstation, but the individual vehicle data is accumulated every minute for transmission back to the RCC for logging and the individual vehicle data (IVD) is discarded. Therefore, any investigation into historical alerts and signal settings will not have full information. There might be indications from the 1-minute data, but often no firm conclusions can be drawn.

It is possible to obtain real-time IVD by plugging a data collection device into the outstation, but for practical reasons this can only be done as part of a formal test/trial at specific sites.
When detectors are commissioned, the HIOCC settings are validated by assessing the appropriateness of the signalling in relation to the traffic. Any queueing traffic should be protected by signals upstream. In addition, signals should not come on when not needed. There are often occurrences of 4-minute settings with no obvious cause. This can be for any of three reasons:

- If the site is close to a junction, then individual vehicles can be slowing to join or leave the motorway. HIOCC alerts are suppressed on slip roads, to avoid setting main carriageway signals, but vehicles can occasionally travel slowly in lane 1 of the main carriageway;
- At any site, individual vehicles can cause valid HIOCC alerts, especially when HIOCC2 is not operational. A vehicle pulling onto/off the hard shoulder will travel slowly, and can generate an alert. The speed limit displayed would be valid, if not necessarily appropriate; or
- A detector can generate a spurious reading. The speed limit displayed would not be valid.

During detector commissioning, checks are carried out on the 1-minute data. Any faulty data is identified, and if it is felt that the data has the potential to set inappropriate HIOCC settings (e.g. the detector data is rapidly changing), then the detector is recalibrated. If this is not possible, then QP can be enabled with that site disabled for HIOCC, with queues detected from adjacent detector sites.

Signalling should be regularly reviewed. If there are multiple instances of 4-minute HIOCC settings at a signal, then the detector generating the alert can be identified and investigated. However, a full forensic analysis of why the signals become set is not normally possible, as the IVD is not stored.

Although the HIOCC algorithm only has a few configurable parameters, it is possible to address some of the signalling issues raised by RCC operators and members of the public. Examples are:

- HGVs travelling up Reigate Hill (J8-9 on the M25) in lane 1 were travelling very slowly and causing 40mph signals to be displayed for much of the day. Although it could be argued that this represented a hazard, there were three additional running lanes and good visibility of the HGVs. Therefore, it was decided to increase the HIOCC threshold for lane 1 to 6 seconds. This was a site-specific solution, not recommended for other locations without careful consideration;
- Messages were being set saying “Queue after next junction” whenever a 40mph limit was being displayed on the downstream link. These were often 4-minute settings and subsequent drivers did not see any signal settings or congestion. Message rules were changed so that this message was suppressed unless a queue had been detected at two consecutive detectors;
- 40mph signals are displayed when there is a queue immediately downstream, and 50mph signals to warn of queues further ahead. With the closely spaced gantries on the M42 Active Traffic Management (ATM) scheme, drivers were seeing 40/50/40 as they drove down the road. This was correct for QP, but driver feedback was that they would prefer to see a consistent 40mph setting, even though this would slow their journey down slightly. The HIOCC rules did not provide an easy solution, but a new CM setting was introduced (see next section) to achieve the desired effect; and
- The HIOCC2 enhancement has improved reliability. The Watchdog check on vehicle speed only delays queue detection by a few seconds. During congestion, once traffic speeds drop below 30mph, that speed is difficult to sustain, and flow is very likely to break down. That means heading quickly into stop/start driving, and there is likely to be only a few seconds between individual speeds of 25mph and 7mph. Meanwhile, the additional Watchdog checks have eliminated some of the spurious settings, both from detector faults and from real, but transitory, events on the road.
The principles of HIOCC were developed based on loop functionality, i.e. presence detectors. Radars emulate loops by generating data that is in the same format. They do this via internal processing. They will emulate HIOCC and HIOCC2 using the same principles. That is another potential gap in the audit trail for how signals get set. As radars are rolled out in more locations, and more tests and trials are carried out on radar capabilities and limitations, the operational characteristics of traffic radars will be better understood. It might be possible for radars to use speeds directly to generate QP alerts, rather than use the HIOCC algorithm, which is based on the operational characteristics of old technology. This would be a potential opportunity for enhancement.

HIOCC operates on most of the motorway network. In principle, wherever there are working detectors, HIOCC can operate. The output method depends on the technology available. In some cases, the only available signals are the MS1 central reserve indicators, which display advisory signals only. On many sections, Smart Motorways (SM) has been implemented, and gantries and/or MS4s display mandatory speed restrictions. Currently, any HIOCC signalling on those sections also uses mandatory speed restrictions, although this is under review (see Section 3.7).

3.5 Congestion Management

CM signalling is primarily based on flow. The principle is that as flows approach the capacity of the road, 60mph signals come on to smooth the flow, reduce lane changing and delay the onset of flow breakdown. As flows continue to increase, the signals change to 50mph. The flow levels at which signals come on are based on the capacity of each link. Typically, each link will have the same thresholds at each site and therefore the same speed limit along the link, although on some long links with a bottleneck at one end, signals are only displayed on the approach to the bottleneck.

As well as managing traffic as flows increase, to delay the onset of flow breakdown, flow-based settings are also used at the ends of peak periods to aid recovery. When schemes were originally installed, this was a minor consideration, but on busy motorways with morning congestion, it has turned out to be a significant benefit. The morning demand flows can increase rapidly, up to and past capacity, and CM can only have a small effect at those times. A greater effect is achieved at the ends of peak periods, and at the start of afternoon congestion.

CM was first implemented on the M25 in 1995. It has been rolled out onto other motorways, and has been given a variety of names. These include Controlled Motorways (M25), Active Traffic Management (M42), 3- and 4-lane VSL (M42), Managed Motorways (Birmingham Box) and SM (the current rollout). All of these refer to the flow-based proactive signalling, as opposed to the speed-based QP warnings.

The CM system is designed to work independently of the QP system. Current policy is that QP is enabled prior to CM on all new schemes. However, from 1995-1998, the scheme on the M25 ran without HIOCC. The CM algorithm also has speed-based thresholds to set signalling during congestion, and to keep flow-based speed limits on during stop-start driving conditions. These were introduced in response to driver feedback, that they did not want speed limits increasing, then switching off, when in queueing conditions. Nowadays, the 40mph QP settings take priority over the 50mph CM settings in queues.

The CM algorithm was originally designed to be highly traffic-responsive, e.g. if a platoon of vehicles was travelling down the road, speed limits would be set to control traffic in the vicinity, then switch off until the next platoon arrived. This would be best for CM while not causing unnecessary delay. However, driver feedback again caused this to be changed. Drivers want to see a consistent set of signalling, with few changes in speed limits. Therefore, heavy smoothing was introduced to damp
down the CM algorithm. There are also separate on and off thresholds, to stop the signals switching on and off if flows fluctuate around the threshold.

The CM algorithm only allows one set of thresholds per site, which have to operate under all conditions. The thresholds are optimised based on the estimated capacity of the road. This capacity can vary according to a number of factors (e.g. weather, light and seasonal effects). Figure 1 shows how capacity can vary from day-to-day on a 4-lane section of the M25. The capacity (the height of each bar) can vary by over 1000 veh/hr on consecutive days, often for no discernible reason.

![Figure 1: Weekday capacities, M25 J13-14 during 1998](image)

Capacity also varies according to traffic behaviour. Lane changing reduces capacity, as does merging at junctions. Capacity is generally lower at junctions than elsewhere on the network. At several locations, e.g. the M42 J6 southbound, the capacity of the road is high in the mornings when traffic is leaving the motorway to head into Birmingham, but far lower (on the same section of road) in the evenings when traffic is joining the motorway. Figure 2 shows a speed/flow plot for this location. In the mornings (the blue points), flows of 100 veh/min are achieved. In the evenings (the green points), flow breaks down at 77 veh/min.
The CM algorithm only allows a single set of thresholds per site. These have to be optimised based on a single expected capacity. This inevitably means that on some days, signals are on too early (or are not needed at all) and on other days, signals come on too late to successfully manage congestion. This threshold optimisation is a complex task, and Highways England has developed a web-based toolkit (Smart Motorways Calibration and Optimisation – SMCALO) to assist optimisation engineers in the task. The balance between signals being on when needed and off when not needed, can be varied from scheme to scheme if required, but it requires expertise and the continued assessment of signalling.

There is also no predictive capability within the algorithm. The algorithm attempts to set signals in advance of flow breakdown occurring, but it has no knowledge of what has happened on other similar days, or of what might be happening elsewhere on the network. The intelligence behind the threshold settings has to be applied in advance by the optimisation engineer.

The CM algorithm has several configurable parameters. Most of these were trialled and then set to suitable values for the first scheme on the M25, and have not needed to be changed on subsequent schemes. In general, the only parameters that need to be determined for new schemes are the on and off flow thresholds for the 60mph and 50mph speed limits. There can occasionally be unexpected effects if traffic does not behave as anticipated in response to the signalling. For example, on the M42, the perception of increased enforcement meant that average traffic speed with a 60mph speed limit was below the 55mph threshold required to switch the speed limits off. This meant that 60mph speed limits were displayed well into the evenings. This was addressed by modifying the speed thresholds (for the West Midlands RCC only).

Knowledge of the algorithm capability can allow novel solutions to signalling issues. Again on the M42, closely spaced gantries meant that drivers were seeing 40/50/40 speed limits (from the QP algorithm). Driver feedback was that they wanted to see consistent signalling, even if it meant slightly slower journeys. Modifying the QP parameters would have had adverse knock-on effects in off-peak periods. Instead, the CM algorithm was modified to allow a new 40mph CM setting based...
on speed, rather than flow. Essentially, the QP algorithm sets 40mph signals, and the CM algorithm keeps them on using the smoothed speed function. Again, this was only implemented at the West Midlands RCC as its use elsewhere would have increased the amount of signalling unnecessarily.

The CM algorithm is primarily designed to smooth traffic on the main carriageway. However, it has been successfully used for CM at complex motorway-to-motorway junctions. Thresholds are set for each individual site based on the road layout (e.g. number of lanes) and traffic behaviour at that site, and signal pointers have been modified to allow main carriageway signals to be set from slip road flows (when the motorway-to-motorway slip road flow is the dominant traffic movement).

There is some flexibility within the CM algorithm, but it requires an understanding of the algorithm’s capabilities and limitations.

### 3.6 Component failure

The two algorithms rely on three elements for their correct operation:

- Detectors (either loops or radar) to collect the traffic data.
- Signals (e.g. gantries, AMIs, signs and MS4s) to disseminate instruction and information.
- Communications (e.g. NRTS) to and from the roadside and the RCC.

These three elements have previously been known as Triple Package. If any of these components has a full or partial failure, it will adversely impact on the operation of the system.

#### 3.6.1 Detector failure

The QP algorithm relies on individual detectors registering slow moving traffic. A loop array comprises a loop pair in each lane, and there are loop arrays every 500m on the motorway network. If a single loop of a pair fails, then HIOCC2 reverts to HIOCC, making the system less accurate, but still responsive. If a lane pair fails, then queues will not get detected in that lane. However, if traffic slows in one lane, it will slow very quickly in the adjacent lanes and queueing traffic will typically be detected within 20 seconds. If an entire set of loops at a site fails, a queue will only get detected when it tails back to the next sensor upstream. During peak periods, this will typically take 90 seconds. There can be an issue overnight – in times of low flow, queues will be slow to lengthen, potentially leaving the queue undetected. However, a similar problem arises if an incident occurs just upstream of a detector; the queue will not be detected until it reaches the next detector.

Overall, the QP algorithm is resilient to an occasional failure. The Detection Rate is not badly affected, and the False Alarm Rate can be managed by disabling faulty detectors until they can be repaired. Only if successive detectors are disabled would the system operation be adversely affected.

The CM algorithm relies on accurate flow data from the detectors. There are several detectors on each link, and as the flow levels are consistent along each link, CM will trigger at all sites at approximately the same time. Therefore, one or two sites that undercount or register no traffic will not have an impact. If a site over-counts, that can cause signals to be on for too long, so that type of fault is a higher priority.

In theory, each detector can be given its own CM thresholds, and in that sense, the CM algorithm is fully flexible to site-specific idiosyncrasies. However, the thresholds cannot be quickly and easily changed, so consistency is required at each site. A fluctuating sensor will potentially cause inappropriate signalling, and would need to be disabled until it could be repaired.
Although loops are in in-road detectors, many so-called “loop faults” do not require any road closures to rectify. The faults are often in the loop connectors, either in the roadside pits or in the cabinets. These faults can be fixed relatively quickly.

Radars use different technology, but emulate loop data and alerts. The types of potential failure and their impacts are less well-known, but the effect on the algorithms will be similar to loop failures.

Detector failures can be mitigated by concentrating repair efforts on those that can adversely affect the signalling. This means giving higher priority to fluctuating sensors, and to locations where two or more consecutive detectors are faulty. Individual faults (especially a complete lack of data from a lane/site) can be treated as a lower priority.

### 3.6.2 Signal failure

A signal failure means that instruction and information will not be able to be transmitted to the drivers. Also, if a single AMI fails, speed enforcement is no longer possible at that site.

The gantry-mounted AMIs have their own internal diagnostics, and if a few LEDs are faulty that would compromise a particular aspect, then the signal readjusts itself to display the aspect in a slightly different position, making the faulty LEDs redundant. In extreme cases, if a speed limit aspect is unavailable, a more restrictive speed is displayed over that lane. However, this makes the speed limits on that gantry unenforceable.

Signal failures are rare occurrences.

### 3.6.3 Communications failure

The MIDAS outstations and the RCC instations are both configured so that if communications are temporarily lost, they continue to try to send the data (traffic data or signal settings). In the vast majority of cases, communication is restored within a minute, and no data or settings are lost.

Long-term communications failures are very rare occurrences.

### 3.7 Summary of Options Report

Highways England has produced an Options Report entitled “Review of the Variable Message Sign and Signal Setting”. The report reviews the policy for setting Motorway Incident Detection and Automatic Signalling (MIDAS) signals and signing. It is primarily concerned with the operation of the QP algorithm, and how to provide information and instruction from the algorithm to drivers and operators. The report uses the term MIDAS to represent the QP algorithm (technically, MIDAS is the means of collecting traffic data and disseminating information/instruction through signalling).

The report identifies 10 potential options for improving the signing and signalling, primarily from an operational perspective with the customer view in mind. These options have been aggregated into five final options:

1. Do nothing;
2. Disable MIDAS signal settings within queues and reinforce with key messages;
3. Review MIDAS thresholds and combine high occupancy algorithm with speed and flow algorithm;
4. Review use of MIDAS Signals to include setting variety of signals e.g. setting signals within queues to ‘20’ as a step down from ‘40’;
5. Public Education.

The report identifies the advantages and disadvantages of each option, from the point of view of benefits, information, technology and safety. Table 7 provides a brief summary of the key advantages and disadvantages.

Table 7: Summary of key advantages and disadvantages of signalling options

<table>
<thead>
<tr>
<th>Option</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| 1. Do nothing           | • No investment required  
                         | • Continued use of familiar information  
                         | • Safety benefits maintained | • Customer satisfaction not achieved  
                         | • Increased delay  
                         | • Increased risk due to customer frustration |
| 2. Disable MIDAS in queues | • QP function is maintained  
                         | • Reduce driver confusion and frustration  
                         | • Increase driver confidence in signalling  
                         | • Setting appropriate messages would keep drivers better informed | • Could cause traffic to speed into back of downstream queue  
                         | • VMS might not be available  
                         | • Need to automate switching off of signals, and need to set criteria for doing so |
| 3. Combine algorithms   | • Signal settings would be more appropriate  
                         | • Make detection less sensitive to lone vehicles  
                         | • Increase driver confidence in signalling | • Increased risk of missing incidents  
                         | • Requires substantial investment in system development  
                         | • Extensive testing required |
| 4. Use 20mph signals    | • No inappropriate queueing information is displayed  
                         | • ‘20’ will more closely reflect traffic conditions in queue  
                         | • Reduce driver frustration | • Increased risk if inappropriately activated  
                         | • Compliance and enforcement would be an issue  
                         | • ‘20’ might not alleviate frustration |
| 5. Public education     | • Reduce customer frustration  
                         | • Customers will understand why signals are set  
                         | • Increase driver confidence in signalling | • Might not have the expected positive impact  
                         | • Challenge of reaching target audience  
                         | • Might be slow to realise benefits |

The report concludes that option 2 would be the most suitable, and suggests that the proposed option should be to disable MIDAS settings within queues and support this by displaying VMS messages that provide more information on reasons for congestion and delay.

The report notes that the assessment only considers the options from a customer value point of view; therefore a cost benefit analysis would be needed to assess the value for money case.

The recommended next steps in the report for this work are detailed as:

- Cost benefit assessment of all options to confirm if recommended options deliver best value for money;
Testing of proposed signs by the customer panel;  
Engaging with VMS policy team to ensure compliance to policy; and  
Development of operational policy for MIDAS.

3.8 Ramp Metering

A third algorithm used for congestion/demand management is Ramp Metering (RM). The RM algorithm does not set any signs or signals on the main carriageway – it sets traffic light signals on the entry slip road to control the entry of traffic onto the motorway.

The RM algorithm uses the upstream flow on the motorway and the downstream speed to calculate the spare capacity on the main carriageway. It then modifies the green time at the traffic light signals to allow an appropriate amount of slip road traffic through. The remaining traffic queues on the slip road.

The principle of releasing traffic onto the motorway in small packets works well, especially at junctions with signalised roundabouts where large platoons of vehicles can travel down an entry slip, having been released by the signals. The success of RM at a particular site can depend on the length of the slip road. Once the slip road is full of queueing traffic, a queue override mechanism switches the slip road signal to green, to avoid queueing traffic affecting the all-purpose network. This releases a large number of vehicles onto the motorway at once, which is the opposite of what RM should be doing. More recent versions of the RM algorithm track the size of the slip road queue, and adjust the green time to stop the queue building to the level required for queue override. This alleviates some of the problems, but it still results in more traffic being released onto the motorway than is ideal. Therefore, most successful RM sites have long entry slip roads.

A minor issue with RM operation is that the traffic light sequence includes the amber and red/amber phases. In other countries (e.g. the USA), the lights switch from red to green to red, allowing single vehicles to pass through. The amber sequences allow more vehicles (typically 5 or 6) to pass.

3.9 Air Quality

Air Quality algorithms are not used on UK motorways. Slowing traffic down to improve air quality has been considered, and the VSL system would be used to display the reduced speed limits. However, the proposed limits would not have been traffic-based; the proposal was that for a fixed period (typically 7am to 7pm), the speed limit would be reduced to 60mph.

This proposal was included in the public consultation for the M1 J28-35a and the M3 J3-4 SM schemes, but air quality signalling was removed from both scheme plans following the consultations.

3.10 Options previously considered

TRL has been assessing the operation of the QP and CM algorithms since 1995, concentrating particularly on operational aspects. During that time, there have been several discussions, both internally and with Highways Agency /Highways England staff, about how the existing algorithms might be improved or enhanced. The discussions concerned the existing algorithms, rather than applying a completely new approach. There were often reasons (e.g. technical feasibility, cost or timescales) why suggestions could not be progressed at the time they were discussed. This section describes some of the options considered.
3.10.1 Validation of QP alerts

QP alerts are caused by individual vehicles, and signals are set as a consequence, without any further checking. The upside of this is that queues are protected as soon as possible; the downside is that false alerts and individual slow-moving vehicles can cause signals to come on. Once on, signals have to be displayed for 4 minutes.

It would be possible to introduce additional checks following an alert. For example, for an alert in a particular lane, it might be possible to check the speeds in adjacent lanes. If these remain high, then the alert is less likely to be due to an event – it could be a false alarm or a transitory slow vehicle at that location. Further research would be needed to determine how many false alerts might be suppressed, whether any real alerts might be suppressed and the delay to setting signals while the checks were carried out.

QP alerts could also be validated longitudinally along the carriageway. A queue could be confirmed by slow traffic at two consecutive detectors, or a queue could be deduced by a lack of traffic downstream of a potential incident. Either of these checks would be likely to take one or two minutes, which would increase the risk of an unprotected queue in the meantime. However, false alarms would be almost entirely eradicated.

3.10.2 Use of VMS for queue protection

QP signalling uses the available technology to display speed limits. For SM, this has traditionally meant mandatory speed limits displayed on gantries (more recently, MS4s have displayed the mandatory speed limits). It is policy that advisory signalling should not be used when mandatory signalling is in use, as this might cause confusion.

The downside of displaying mandatory signalling is that traffic is slowed unnecessarily if there are false alerts. The signalling is displayed for at least 4 minutes so many vehicles will be affected.

A possible alternative when MS4s are in use would be to continue to use mandatory signalling for CM settings, but to use pictograms and/or messages to warn drivers of queues ahead. The advantages of this would be that false alerts would not slow drivers unnecessarily, drivers would be better informed of the reason for the signalling, and they should have a heightened awareness of problems ahead. The disadvantage would be that some of the safety benefits from HIOCC might be lost if drivers are not forced to slow down.

3.10.3 Using site data to hold additional thresholds

At the moment, only one set of CM thresholds can be held in site data. This set of thresholds has to apply for all seasons, weather conditions, times of day, bank holidays etc. The SMCAOL toolkit helps traffic engineers to optimise the signalling for a scheme. However, this optimisation is often a balance between mornings and afternoons, with signals on when not needed in one peak period and off during congestion in the other peak period.

There would be significant benefits to the signalling to have two sets of thresholds, one for the morning and one for the afternoon/evening. The algorithms would require changing so that the system knew which set to apply. The benefits would arise from having appropriate CM when needed, and not slowing drivers unnecessarily at times of the day when capacity was higher.
3.10.4  **Swapping sets of site data**

The single set of thresholds in site data also has to apply for all times of the year. In general, capacity is higher during the summer months, and so signalling would ideally be on less (assuming the same traffic flows). This is a longer-term effect than the AM/PM differences discussed above, and could be achieved by modifying site data once or twice a year to introduce seasonal thresholds.

In the past, lead-in times for site data installation ran into months, due to testing etc. Highways England has recently developed a procedure that would allow different sets of site data to be held at an RCC, and swapped at relatively short notice. This procedure is useful when SM are being switched from 3-lane running to All Lane Running (ALR), but it could also be used to introduce new sets of seasonal thresholds.

3.10.5  **The effect of weather on capacity**

The single set of thresholds in site data also has to apply for all weather conditions. Logically, the capacity during rain and/or fog should be lower, as drivers leave longer gaps to the vehicle in front. Signals that came on earlier during poor weather conditions would help to manage the traffic better.

TRL carried out some internal research into the effect of weather on capacity\(^1\). The report was not conclusive, but more work could be carried out into how capacity varies to determine the potential benefits of adding a weather-related element to the algorithm. At this stage, it appears that the added complexity for the algorithm would not justify its inclusion. The random fluctuations in capacity (as shown in Figure 1) appear to be greater than any weather effect.

3.10.6  **Predicting demand flows and flow breakdown**

All day types (days of the week, bank holidays, school holidays etc.) are treated the same by the algorithm. Studies of traffic patterns have shown that congestion occurs at regular locations on certain days, but there can be no queueing on other days. If the CM algorithm had a predictive capability, it would be better able to anticipate when congestion would be likely to occur. This in turn would lead to more appropriate signalling.

Research into predicting flow and speed profiles has shown that the best predictive mechanism is “same as it was last week” (or to be more precise, same as it was on the last of the same day type). A combined historic and predictive model would be able to compare the current flows with previous days of the same type, and predict when flow breakdown was likely to occur.

This proposal could potentially provide more appropriate signalling, but it would involve significant changes to the CM algorithm.

3.11  **Other considerations**

This work package includes a consideration of two further options: a link-based system and operating the algorithms from the instation.

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\(^1\) External Factors Affecting Motorway Capacity (PPR534)
3.11.1 *Link-based system*

The proposal would be to use a system that sets signals over a whole link, rather than based on individual sites.

The benefit of this would be to provide consistent information for drivers for the length of their journey along the link. A link-based system might also be able to utilise fewer signals (one at the start of the link might be sufficient), and fewer detectors (although for the QP algorithm, fewer detectors would reduce the Speed of Detection).

For the QP algorithm, having a link-based system would introduce major disbenefits. Signals to protect queues would need to be set for the whole link, irrespective of where the queueing was. This might lead to drivers being forced to travel at 40mph for considerable distances having passed an incident. There would also be a disbenefit further upstream – the current lead-in signalling is sufficient to give drivers plenty of warning and space to slow down. Introducing additional upstream signalling would slow drivers unnecessarily.

For the CM algorithm, the default is to have the signals set along a whole link. The SMCALO toolkit divides the road into sections, with each link being a section. It then calculates the optimum thresholds and applies these to the whole section. Signals will switch on and off at approximately the same time along the whole link. Therefore, although the CM algorithm allows separate thresholds for each detector, it already operates as a link-based system at several locations.

However, the CM algorithm also has the flexibility to allow site- or area-specific signalling. On a long link with a busy junction at the end, the capacity at the junction is likely to be considerably lower than on the rest of the link. The traffic needs to be managed on the approach to the junction, but setting signals along the whole link would delay drivers unnecessarily. SMCALO has the facility to define sections within a link, where the signalling will change. These sections and the boundaries between them are fully configurable by the optimisation engineer. Within each section, drivers are presented with a consistent bank of signalling.

Introducing a link-based CM algorithm would mean that fewer detectors would be needed. However, the detectors would still be needed for the QP algorithm, and the current CM algorithm has the facility to disable detectors for CM if required.

In conclusion, introducing a link-based system would result in more inappropriate signalling, delaying drivers unnecessarily. The benefits would be minimal.

3.11.2 *Running algorithms from the instation*

Currently, both the QP and CM algorithms run at the outstation, so signals are only set based on the flows/speeds/occupancy at a single detector. The advantage offered by running at the instation level would be that the data from more than one detector could be combined and/or compared to produce a more reliable detection (for QP) or management plan (for CM). The disadvantage of this is that for QP, it may take more time to process so the Speed of Detection would be likely to be worse. For CM, the algorithm would be more complex, without necessarily improving the system significantly.

Examples of algorithms combining data from multiple detectors would be:

- Only setting a QP setting when two adjacent/upstream/downstream sites have detected a queue.
- Where a regular congestion seed point is caused by a merge or diverge, the data for sites upstream and downstream of the junction could be compared to produce CM settings based
on the amount of traffic joining/leaving the road in addition to the raw amount of traffic at the congestion seedpoint.

The disbenefit of the reduced Speed of Detection for the safety critical QP settings would need to be assessed against the potential benefits of reduced spurious settings. There would be reduced delay, but at the expense of increased risk. For CM, there is a lot more scope for this kind of analysis as regular congestion seed points often occur around junctions and the amount of weaving as traffic joins and leaves the motorway is a big factor in the formation of this congestion. However, implementing an instation algorithm that combined data from a number of sites would require significant design and testing.

### 3.12 Conclusions

The current QP and CM algorithms have survived in their current form for over 20 years, partly because replacing them would be expensive, but partly because they perform their function relatively well, and provide considerable benefits, especially to safety.

The QP algorithm is designed to be highly responsive. It provides a very high Detection Rate, a very quick Speed of Detection and a very short Clearance Time. The downside is that there is a high False Alarm Rate. Alternative systems or modifications to the current algorithm would provide fewer false alerts, but would be likely to leave queueing traffic unprotected more often.

The current QP system can produce two types of “false alarms”. The first is a “real” fault, caused by a detector malfunction. The second is a valid reading, caused by a single slow vehicle, but the requirement for QP signalling might only last for a few seconds. The QP system could be modified in two ways:

1. Introduce additional checks into the algorithm before setting signals. This would greatly reduce the number of inappropriate settings, but at the expense of leaving queues unprotected for longer. The exact balance would need to be investigated further.

2. Modify the signalling strategy so that the impact of the false alarms is mitigated. Examples could be to reduce the 4-minute minimum on time so that inappropriate signalling was displayed for shorter periods, or to use messages to warn of queues rather than mandatory speed limits. Both of these modifications would have potentially detrimental side-effects (to signal variability and to safety respectively), and would need to be investigated further.

The QP system could also be slightly modified to address driver satisfaction. Highway England’s Options Report has identified several options, but these are largely cosmetic, and do not address the core functionality of the algorithm.

All of the above possibilities, or indeed the introduction of a new QP method, would require a trade-off between detection rate, speed of detection and false alarm rate. This could be treated as a pure business decision, based on Treasury values for delay and personal injury, or could be weighted more in favour of one aspect. The current system is heavily weighted in favour of safety, and is at the extreme end of the safety/delay balance for all the options and/or systems available.

The CM algorithm provides some operational flexibility, but is hampered by only having a single set of flow thresholds for all times of days, seasons, weather, day types etc. It also has no predictive capacity, either in comparing current conditions against historical data, or in anticipating demand from conditions elsewhere on the network.

Introducing a predictive capability would be a complex task, and possibly not worth the expense given the potential benefits. Introducing the facility for separate sets of thresholds according to various factors would be likely to be easier to implement, and would provide the opportunity for
more appropriate signalling. It would still require considerable design and testing, but the business case for this could be better.

The current CM system provides an appropriate level of responsiveness, with low variability in the signal settings. The algorithm provides the opportunity to vary the responsiveness if required; major changes to the existing design do not appear to be needed.
4 WP3000: Consider algorithms for forthcoming expressways

4.1 Purpose
Highways England plan to convert a number of trunk roads in England to ‘Expressways’. These will be “A-roads that can be relied upon to be as well-designed as motorways and which are able to offer the same standard of journey to users.” It is planned that these roads will use the same algorithms for QP and CM as SM. This work package considers the implications of implementing the algorithms discussed in work packages 1000 and 2000 on these new expressways.

4.2 Methodology
A technical note was produced in March 2016 to “document the high level core requirements which shall be present for a route to be designated an expressway”. The information in this document has been analysed to identify areas where differences between these roads and motorways may require variations in the identified algorithms.

4.3 Results
The Expressways Technical note summarises expressways as:
“A-roads that can be relied upon to be as well-designed as motorways and which are able to offer the same standard of journey to users. At a minimum this means:

• Largely or entirely dual carriageway roads that are safe, well-built and resilient to delay;
• Junctions which are largely or entirely grade separated, so traffic on the main road can pass over or under roundabouts without stopping;
• Modern safety measures and construction standards; and
• Technology to manage traffic and provide better information to drivers.

This means an expressway will be able to provide a high-quality journey to its users. Most expressways should be able to offer mile a minute journey throughout the day, particularly outside of urban areas. Safety levels should match the highest standards of the network and, for many parts of the country; an expressway will be able to provide a motorway-quality journey for drivers.”

The document lists the core requirements for expressways. These are presented in Table 8 with notes about their potential effect on algorithms.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Adaptations needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>“A route or scheme can only be designated as an expressway if all of the core requirements are present and the length exceeds 10 miles or the terminal junctions intersect with another expressway, motorway or edge of conurbation/major transport hub such as an airport.”</td>
<td>This means that all the requirements below should be fulfilled so variations from these do not need to be considered.</td>
</tr>
<tr>
<td>“Expressway designation gateway and exit signing. [Consideration being given to introducing a new class of road].”</td>
<td>Allows the provision of variable mandatory speed limits so no variation to the algorithms is needed.</td>
</tr>
<tr>
<td>Requirements</td>
<td>Adaptations needed</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>“Maximise opportunities for environmental, aesthetic and community enhancement of expressway corridors. Requirements and advice to be determined.”</td>
<td>This should not have an effect on the algorithms</td>
</tr>
<tr>
<td>“Non-motorised Users (NMUs) and slow moving vehicles shall be prohibited from using an expressway. Where practicable, alternative provision shall be considered so that NMUs journey experience should at a minimum, be no worse for any group than before the implementation of the scheme. This will need to be assessed on a scheme by scheme basis and considered at a regional level.”</td>
<td>Algorithms will not need to be adapted if slow moving vehicles are not using expressways. Unnecessary signals can be set by slow moving vehicles.</td>
</tr>
<tr>
<td>“Highest quality geometry dual 2 or 3 lane all-purpose trunk road (APTR) carriageway operating at national speed limit; clearway; grade separated junctions or left only movements; and no central reserve gaps. In addition to these requirements there shall be no direct public access/egress to/from an expressway other than at junctions with ‘B’ classified roads or greater.”</td>
<td>Algorithms will not need to be adapted for slower speed limits, vehicles parking on the side of the road or vehicles slowing down on the approach to right turns at central reserve gaps and roundabouts. Most roads will have fewer junctions than they presently do, however this may still be a greater number than existing motorways. Consideration of the impact of this may be needed. Consideration may also be needed of the effect of traditional left turn junctions (as opposed to slip roads). The current CM algorithm has been tuned for 3-lane and 4-lane carriageways. It is not currently used on any extensive sections of 2-lane carriageway. The impacts of this will need to be considered.</td>
</tr>
<tr>
<td>“Central reserve rigid concrete barrier (RCB) shall be provided.”</td>
<td>This should not have an effect on algorithms.</td>
</tr>
<tr>
<td>“Emergency turnaround provision - emergency crossing points shall be provided in the central reserve and shall be supplemented by hardened verges (where required) to support vehicles with a large turning circle. Where practicable, consideration shall be given to co-locating emergency crossing points with emergency refuge areas (ERAs) to provide the required turning area.”</td>
<td>As this should only be used in an emergency when signals will already be set by queuing traffic, consideration is not needed in algorithms.</td>
</tr>
</tbody>
</table>
Overall, five potential differences between expressways and motorways have been identified that may need consideration in applying QP or CM algorithms to expressways:

1. Possible closer spaced junctions
   - This has the potential to cause traffic from a merge to still be settling into lanes when traffic starts to move for the next diverge causing increased weaving that may impact on the running of algorithms
   - More site-specific CM thresholds might be required

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Adaptations needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>“VMS for incident/traffic management with wind down or ladder access. Signing/carriageway signalling and customer information with spacing/visibility requirements in accordance with IAN 161 – the requirements for smart motorways. Provision of variable mandatory speed limits (VMSL) for congestion management. Compliance and enforcement measures are to be determined.”</td>
<td>These are the same requirements as SM so no adjustments to the algorithms are needed.</td>
</tr>
<tr>
<td>“Standardised ERA design that is consistent with a smart motorway ERA design except the expressway requirements includes double yellow lines and it is combined with a maintenance hardstanding area. ERAs co-located with VMS sites (refer to Annex C) to also facilitate maintenance access – technology devices shall be clustered at an ERA wherever practicable.”</td>
<td>The only difference here is the addition of double yellow lines which should not have an impact on algorithms.</td>
</tr>
<tr>
<td>“Provision of an above ground traffic detection system.”</td>
<td>Consideration may be needed to ensure the expressway environment does not have an adverse impact on the operation of a system tested on motorways.</td>
</tr>
<tr>
<td>“Pan-tilt-zoom (PTZ) closed circuit television (CCTV) cameras providing comprehensive coverage.”</td>
<td>This should not have an effect on algorithms.</td>
</tr>
<tr>
<td>“Technology assets integrated into Highways England traffic management system (CHARM) controlled from regional control centres (RCC).”</td>
<td>It has been assumed that this will be the same with SM so no adaptations to the algorithms will be required.</td>
</tr>
<tr>
<td>“Traffic Officer ‘On road’ and Control Centre support – service level is currently being determined to meet the performance objectives.”</td>
<td>This should not have an effect on algorithms</td>
</tr>
<tr>
<td>“Off network rest/service areas at not more than 28 mile intervals and no more than 30 minutes driving time apart in accordance with TD 69 and DfT Circular 02/2013 “The strategic road network and the delivery of sustainable development.”</td>
<td>This should not have an effect on algorithms although if any parking laybys are retained the effect of these may need to be considered.</td>
</tr>
<tr>
<td>“Junction numbering and ‘on road’ reference (e.g. 500m spaced driver location signs) system.”</td>
<td>This should not have an effect on algorithms</td>
</tr>
</tbody>
</table>
- If parameters are varied on a link by link basis, it is possible extra time will need to be allowed to choose these parameters if there are more links for the same distance of road.

**Further investigative work:** existing locations with the algorithms running on closely spaced junctions could be studied to either develop a methodology for these sections or conclude that no special consideration is needed.

2. Left turn junctions (in contrast to slip roads)
   - Vehicles need to slow down more to make a left turn which may lead to an increased application of QP signalling. It may be possible to mitigate this with site specific parameters for these locations or by disabling individual detectors where necessary
   - The same is also true of vehicles accelerating after joining from a left turn without a slip road.

**Further investigative work:** if these are to be included in expressways, a study may be needed into driver behaviour at these locations and how this will affect the algorithms. This could include installing a detector at a relevant test site to understand the alerts which may be generated.

3. Two lane roads
   - The existing algorithms (particularly CM) were developed for a system largely deployed on three or more lane roads. All algorithms should be assessed to ensure they will have benefits on the largely two lane expressways’ network

**Further investigative work:** the QP algorithm runs on some two lane parts of the A14. A study could be undertaken to check this operates as expected. Additionally, it is possible that a simulation of the CM algorithm could be run on this section using the same methodology as that used in optimising existing SM schemes. This would allow any likely issues to be understood.

4. Operation of detection systems
   - The new above ground detection systems have been tested on three lane and four lane motorways. Any variations in their operation on two lane roads with different geography may need to be taken into account

**Further investigative work:** a trial may be needed to understand the operation of the above ground detectors in the specific geography of a two lane road after identifying any differences that may have an impact.

5. Impact of laybys
   - The technical note does not state that existing laybys on trunk roads will be closed when they are converted to expressways. If this is the case, vehicles slowing down to enter a layby or accelerating to leave a layby may trigger QP signals. This will need mitigation in the same way as left turns above

**Further investigative work:** similarly to left turns, if these are to be included, a study/trial of these sites may be needed to ensure all problems are mitigated.
WP1000 has not identified any algorithms for QP or CM that would be more suited to expressways than those used in SM. Therefore, changes that may be beneficial to expressways are the features that can be changed within the existing algorithms:

1. Spacing of signals
   - The Basic (Rural) Controlled Motorways project in 2006/7 assessed the impact of spacing gantries further apart. This was further considered during the development of all-lane running SM. The dis-benefit of this is that there is a longer time period between instructions to drivers, so more vehicles will pass an incident without seeing any warnings of that incident, and instructions and information will be less targeted to the particular incident. It is unlikely that there would be any benefit in applying wider spaced signalling on expressways.
   - The original M42 Managed Motorways section has gantries more closely spaced than standard. This has not been repeated elsewhere when Managed Motorways have been installed. It may be of benefit if an expressway is less straight than motorways generally are, to improve intervisibility between gantries.

Further investigative work: assess whether any of the forthcoming expressways would benefit from closer spaced gantries to improve intervisibility.

2. Spacing of detectors
   - The Basic Controlled Motorways project also investigated increasing the spacing between detectors. This has the major disadvantage of increasing the time until a queue is detected and therefore protected. This would not be recommended for expressways since it would reduce the level of safety they could provide.
   - The original M42 Managed Motorways section had loops spaced every 100m rather than the usual 500m. This was not found to provide a significant benefit in detection performance, so when the original loops were replaced with radars the spacing reverted to the standard 500m spacing.

Further investigative work: none recommended.

3. Type of detectors
   - Two types of detector have been used in SM operations in the past: inductive loops and side-firing radars. These each provide data to outstations in the same way for processing. There may be benefit in assessing the market for a different detector that is more suited to expressways; and

Further investigative work: assess whether any products exist which are more suited to expressway spot detection than the existing loops and radars.

4. Parameters used within the algorithms
   - There are a number of parameters within the algorithms that can be modified either on a site or regional basis. It is possible that different values of these parameters may be better suited to the expressway environment. For example, there may be benefit in setting more, fewer or different signals in response to a queue.

Further investigative work: a study of the impact of changing QP and CM algorithm parameters in the expressway environment.
5 WP4000: Investigate air quality algorithms and horizon scan future developments

5.1 Purpose

The purpose of this work package was to review upcoming developments to air quality schemes and algorithms as well as future developments to in-car systems and their application.

5.2 Methodology

A desk-based literature review was carried out as in work package WP1000. The two key areas of focus for this literature review are: air quality algorithms and motorway schemes; and future developments to in-car systems and communications. The challenge encountered by the horizon scan for new developments was that there are a very small number of trials or proposed schemes which use novel algorithms to actively manage air quality as the primary concern of traffic management. As a result the current motorway management schemes which use familiar elements of the UK’s SM schemes to reduce air pollution are summarised.

To gather the largest volume of relevant information possible, this work package was approached by constantly expanding search terms and criteria to gather all available information with regards to air quality and changes in detection and communications technology. The team started with a very narrow focus to find the most relevant lines of enquiry, and when these were exhausted the search was expanded to include broader enquiries.

This approach was fundamental to capturing developments which are relevant for this work package given the scarcity of information available for novel systems and approaches. This information was filtered from the results summarised in Appendix E and is presented below.

5.3 Results - literature review: air quality

While many traffic management systems produce quantifiable benefits in air quality, this is a desirable side-effect of the general traffic flow smoothing produced by advanced traffic management such as the UK’s SM concept. Existing schemes such as VSL and all-lane running (ALR) have shown modest reductions in vehicle emissions both in the UK and abroad. For example VSL on four lane roads was shown to reduce emissions by 4-10% (Highways Agency, 2008)\textsuperscript{37}.

These measures improve air quality by reducing congestion which is mutually beneficial to road users and the environment and does not require any significant trade-offs between journey times and emissions to be made in optimisation. However in a motorway setting there are also air quality benefits from lowering the cruise speed of vehicles by implementing a reduced speed limit. A balance is needed between the competing requirements for swift progression along the network, and the most appropriate speeds for emission reductions.

Therefore focus of this research moves away from air quality improvements as desirable side effects of existing traffic management systems, which are well documented, to focus on the development of traffic management techniques and methods which have the reduction of emissions as their main focus.

Although the aim of the systems is to improve air quality, local air quality measurements are difficult to compare, as they are highly dependent on the prevailing weather conditions. Therefore, most air quality schemes are assessed on their effect on emissions. In addition, most air quality schemes are
either fixed time plan or driven by traffic conditions. Only a few are driven by current or predicted air quality – see the following sections for examples.

5.3.1 Reduction of speed limits effect on emissions

As mentioned in Section 3.9 blanket daytime speed limits were considered for UK motorways, for the explicit purpose of emissions reduction but were dropped from proposals after consultations.

The implementation of a set (non-reactive) reduction in the speed limit can be easily achieved by VSL signs and its applicability for improving air quality on motorways has been demonstrated in several European studies and associated simulations. Blanket changes to the speed limit can be examined in terms of efficacy regardless of whether VSL infrastructure is used to implement the limit or not, as the overall effect is the same.

Early examples of the introduction of set speed limit reductions to improve air quality are found in the Overschie district of Rotterdam (Netherlands) where the speed limits on the A13 ring road (which is a national motorway) were reduced to 80kph in 2002 (Olde et al., 2005). This produced reductions in pollutants, of around a 14% decrease in NOx, although the average speed dropped by around 20kph (Olde et al., 2005). Similar changes in the speed limits were subsequently introduced at other ring road motorways in the Netherlands, including Amsterdam. In Amsterdam the speed limit was reduced from 100kph to 80kph. This resulted in a reduction in emissions but increased congestion along the controlled stretches (Dijkema et al., 2008).

However an inflexible speed limit can have negative consequences which were not captured in the initial studies. Research by the Centre for Transport and Navigation in the Netherlands examined reductions in the speed limit on motorway ring roads and concluded that these schemes had the side effect of pushing traffic onto the secondary network around the city and that viewed as a whole the reduction in pollution in the area was minor, NOx reductions were only 0.5% when examined across the total network (Stoelhorst, 2008).

Similarly to schemes in the Netherlands, motorways feeding into Barcelona were subject to an 80kph speed limit (reduced from a maximum of 120kph). This scheme ran concurrently with the introduction of VSL infrastructure on other parts of the network in 2009. A study which investigated the effect of the set reduction of the speed limit predicted a reduction in total emissions of 4% (Baldasano et al., 2010). However a more recent analysis by Bel and Rosell in 2013 concluded that the fixed speed limit had in some cases increased NOx– in the overall area by 1.6 - 2.5% (Bel & Rosell, 2013).

5.3.2 Setting variable speed limits in response to air quality stimulus

Traffic responsive air quality measures are harder to implement cost-effectively because the bulk of emissions savings are already achieved by motorway management and ramp metering which optimises for traffic flows rather than emissions. Further savings require a general reduction in cruise speeds, which can adversely affect journey times. These factors contribute to the general lack of schemes uncovered by our research which actively seek to manage air quality as a primary driver for optimisation.

That said a consistent theme in our research into air quality improvement schemes on motorways is that varying the speed limit dynamically to reduce pollution provides a more effective solution than a set reduction in the speed limit, and can reduce emissions generally at some cost in journey time (Bel & Rosell, 2013), (Stoelhorst, 2008).
However the concept that VSL which are not optimised for emissions reductions always outperform a fixed speed limit (set with the goal of emissions reductions) is not universally supported by our research. A Belgian study used a microsimulation of a corridor of the E313 motorway to compare the effects of VSL (not using air quality algorithms) against a set speed limit reduction displayed via the VSL signs. This study found that setting a permanent maximum speed of 90kph would decrease vehicle speeds by 4.25% but this reduction would reduce NO\textsubscript{x} emissions by 2.03% and CO\textsubscript{2} by 1.18% (Degraeuwe et al., 2012).

One of the most prominent examples of a coordinated attempt to optimise traffic flow for emissions reductions comes from the Netherlands. The DYNAMAX project was undertaken in Holland to investigate the effects of so called ‘dynamic speed limits’ (where a VSL is set based on a stimulus). This was intended partially to investigate ways to overcome the shortfalls of a set reduction in speed on motorways by employing VSL at four field test sites.

The four sites all tested different elements of traffic management. One site, on the A58 near Tilburg, had the sole stated aim to improve air quality (Stoelhorst et al., 2011). The dynamic speed limits on this stretch of road were set by an algorithm that used forecasts from the Royal Dutch Meteorological Institute as to the concentrations of PM10 five days in advance, rather than based on local measurements (Stoelhorst et al., 2011). In this trial the speed limit was reduced from 120kph to 80kph when exceedances in legal daily limit values for the concentration of PM10 were anticipated. During the six month trial this limit was triggered 14% of the time. The results of this trial were that PM10 and NO\textsubscript{x} emissions due to road traffic declined by 18% and the number of days that the PM10 limit was exceeded was reduced annually by two days. However travel time increased by 10-15% (Stoelhorst et al., 2011).

Theoretical studies in the UK have previously shown that similar improvements in air quality can be achieved on the UK network in several ways: firstly via reducing the speed limit to a predetermined value when traffic detectors register a flow per hour above a set threshold; secondly through increased use of ramp metering; and thirdly by varying the speed limit in response to exceedances in pollutant concentrations (Bell et al., 2006). Varying the speed limit based on flow data yielded a maximum hourly reduction in NO\textsubscript{x} of 3.5-5.1% depending on the differing thresholds used (Bell et al., 2006), this is the mildest reduction demonstrated in the study but is also the easiest to implement. This study showed that ramp metering reduces emissions significantly and since the study was conducted ramp metering has become has become common on the UK’s motorway network. The largest benefit came from varying the speed limit in response to measurement of emissions at the roadside, however this would require investment in a sensor network and would make the system reactive rather than proactive.

The use of forecasting and climate modelling as in the DYNAMAX field trials in the Netherlands would eliminate the need for a large emissions sensor network and make the system predictive rather than reactive. The use of cooperative systems and in-car units will also change the way that air quality is managed on the motorway as described in Section 5.4.1. Here we examine in more detail the benefits to both journey times and air quality that VSL systems with access to in-car data can provide to a motorway network.

5.4 Results - literature review: future development

This part of the horizon scan focused on the use of cooperative vehicle systems in traffic management. The broad phrase ‘cooperative vehicles’ (sometimes styled ‘connected vehicles’) includes vehicle-to-vehicle and vehicle-to-infrastructure communications (V2V and V2I respectively in common parlance, also generically called V2X). Cooperative systems allow each car in the network to become a source of data. An increasing degree of penetration of these systems would eventually
make existing sensors used on the motorway network obsolete and produce significant cost savings for road authorities (Ball et al., 2013)[5]. This leads to the concept of a cooperative intelligent transport system or C-ITS. The future applications of this technology in many forms, such as autonomous vehicles, will entirely change the nature of traffic management but remain a distant prospect. Therefore we have chosen to examine the state of the possible with regards to cooperative systems and in-car units. The findings of our research are broken down into two sections.

The first comprises the motivation for using data available from connected vehicles and the use of in-car displays. This includes theoretical improvements to optimisation algorithms, the automatic detection and reporting of incidents and the detection of queues on the motorway.

The second section summarises key developments in the communications technologies used in cooperative systems and how such systems are practically implemented in field trials and some pre-commercial systems.

5.4.1 Benefits of cooperative systems to existing ITS

5.4.1.1 Optimising emissions and travel time through cooperative systems

A focus of research by several authors has been how to use cooperative systems in the motorway environment; several projects were found which examined how to reformulate the algorithms used in setting VSL to take advantage of the increased data offered by cooperative systems. The types of data acquired and the communications systems which would be used are all possible with today’s technology.

Grumert & Tapani (2012)[34] demonstrated that the dissemination of VSL to in-car displays via roadside units can bring mild improvements in efficiency and emissions simply by communicating the change in speed limit to vehicles sooner than a gantry-only system could. This microsimulation indicated modest savings of 1.52% in fuel consumption using in-car units to display the VSL in comparison with a contemporary gantry VSL system. The mean speed of the in-car system was lower but no significant increases in overall travel time were observed which the author attributes to smoother traffic flow than in a conventional VSL system (Grumert & Tapani, 2012)[34].

Grumert (2014)[33] built on this work to examine potential differences between a contemporary VSL system with a cooperative VSL (C-VSL) system which makes use of two way communication with individual cars. This system is more nuanced than in previous work. The author lists the advantages of this new C-VSL system as: the ability to communicate changing speed limits earlier than a traditional gantry system; individualised speed limits per vehicle determined by their current speed and position; and that individualised speeds can be automatically implemented via integration with cruise control (Grumert, 2014)[33]. Novel algorithms for the control of a C-VSL system are formulated by the author and assessed using the SUMO microsimulation software. This is assessed for a period of 20 minutes at 4400 vehicles per hour, which equates to 70% of the capacity of the modelled stretch of motorway (Grumert, 2014)[33]. The results of this comparison between a standard VSL and a C-VSL system indicate that a C-VSL system produces a 9.4% reduction in NOx and a 15.3% reduction in hydrocarbon emissions. The C-VSL has a higher mean speed than the VSL system due to a higher degree of homogenisation of the traffic flow, however for the same reason it also has a lower mean standard deviation of speed than a traditional VSL system which is not capable of smoothing traffic to the same degree (Grumert, 2014)[33].

Khondaker & Kattan (2015)[41] used VISSIM microsimulation to evaluate an algorithm formulated by the authors which utilises data likely to be available from connected vehicles to optimise and control
Algorithm Improvement

VSL settings. The study optimised VSL setting based on three factors; travel time, safety and fuel consumption. This work compares two different penetrations of connected vehicles of 50% and 100% with a base scenario with no VSL control. While there was no direct comparison with existing VSL algorithms the research highlighted that in an environment with 100% penetration of connected vehicles optimising for any of the three factors would produce reductions in collisions, travel time and emissions across the board. However in a lower penetration rate of 50% optimising for fuel consumption or travel time can have a negative impact on collision probability (Khondaker & Kattan, 2015). This highlights the potential considerations for the use of cooperative systems in optimisation as they become more widespread in the national fleet.

Approaching the issue of speed and emissions management from a purely in-car perspective (Barth & Boriboonsomsin, 2009) examined the use of an in-car unit to display speed advice to the driver in real time which was calculated based on flows from the existing California Freeway Performance Measurement System (PeMS) which makes use of inductive loops to monitor Freeway traffic. These in-car units helped drivers optimise their speed for emissions and also provided speed data from the car back to the central system. These advisory units produced a 10-20% saving in fuel without a significant increase in the overall travel time in both simulated and real world experiments (Barth & Boriboonsomsin, 2009). This demonstrates the mutual benefits of two way communication between the infrastructure and the road users, albeit with the condition that close obedience to the speed advice is required to realise these benefits.

5.4.1.2 In-car incident detection

There are numerous traffic systems which provide various different applications; one of the most developed is ‘eCall’ (Mocanu et al., 2014). eCall is a safety system which calls the emergency services in the event of the system detecting when the vehicle has crashed, or when the driver manually pushes a button. This in turn creates a faster response time to the incident, thus reducing the time in which the vehicle might be creating congestion, as well as heightening the chance of the occupants surviving the crash. Currently eCall does not interface with traffic management directly which would allow a more direct impact on congestion and incident management from a Road Authority’s perspective. With eCall being made mandatory by the EU there is potential in future developments which would allow eCall to interface with roadside infrastructure to further increase safety.

As it currently stands, eCall has the side effect of easing congestion due to the vehicle(s) being cleared quicker because of a faster response time, with the reduction in delay being estimated at being between 5% (Geels, 2004) and 10-25% (Abele et al., 2005). Not only does this function help with reducing congestion in its own right but the alert can then also be used in conjunction with other in-car warnings, such as WLD (Wireless Local Danger Warning), warning drivers of traffic ahead through vehicle-to-vehicle communication. This data could be taken even further and use intelligent speed adaptation to control speed when approaching the vehicle. Speed Alert is one such system, which is a map and camera system, informing the driver of static, informal and VSL. The system has been introduced in two stages, one stand-alone system in 2010, which “gives speed limit advice based on static and fixed time dependent speed limits” (Wilmink et al., 2008) and one stage planned in 2020, which takes information from traffic centres, VMS and beacons and gives speed advice based on recommended speeds, not just the actual speed limit. This functionality is in line with the theoretical proposals outlined earlier in this section.
5.4.1.3 In-car units and queue detection

Netten et al., (2013)\textsuperscript{54} investigates via simulation, an extension to the DYNAMAX project (mentioned previously) which uses in-car units and roadside infrastructure to expand the capabilities of the system. The purpose of this paper was to improve the detection speed of the end of emerging queues.

The in-car units provided related vehicle position and speed data while providing dynamic speed advice directly to the driver; the authors assert that this could be realised with either cellular communications or ITS G5 802.11p wireless communications. This in-car data was ‘fused’ with information from inductive loops and camera tracking to provide a hybrid data set. The performance of the system was assessed using: detection delay; accuracy of the queue tail location; and the accuracy of the length of the queue. The report concludes that the additional data from the cooperative system reduces the average detection time and improves the accuracy of the end of queue and length of queue predictions. In a scenario with only 1% penetration of equipped vehicles the detection time is reduced by 1.5 minutes (to an average time of 40 seconds) over a non-cooperative system using inductive loops only (Netten et al, 2013)\textsuperscript{54}. These savings are dependent on the frequency of the inductive loops on the network – Netten used the same 500m frequency as found on HE motorways. This research highlights the effectiveness of cooperative data even at very low penetration rates that could be realised in less than five years.

5.4.2 The current state of cooperative-ITS technology

The following sections outline the current developments and testing of cooperative systems and their interfaces with ITS. This section focuses on the technology which facilitates V2I and V2V communication. As a result this section includes some projects which have limited relevance to motorways from a traffic management perspective because the technology employed is likely to be used in a motorway environment. For further details on communication technology specifics, see Appendix D, which contains information on common methods of communication and protocols currently used in cooperative systems.

Whilst cooperative systems offer benefits for both the user and Road Authorities, the systems do rely on uptake of new vehicles on the road having cooperative capability to maximise their potential. The Connected Car Study 2015 foresees the annual sales of connected car technologies tripling to €122.6 billion by 2021 (a growth of 204% from 2016 to 2021), which is a slight slowdown compared with earlier estimates (Viereckl et al., 2015)(a)\textsuperscript{77}. Security concerns have been a factor regarding the public perception of internet enabled vehicles and auto makers have countered these qualms by embedding security “in every aspect of their design” (Viereckl et al., 2015)(b)\textsuperscript{78}. Despite this new added technology to vehicles, prices have only risen by around 4%, enticing more customers to buy a connected car. On the other hand, the connected vehicles’ market is seeing competition from third-party aftermarket sales, such as TomTom and other smart applications. These are a lot cheaper in comparison with the relatively expensive initial cost of a connected car, when a lot of users can pay a smaller amount for an application on their smart phone. EU mandate dictates that all auto makers must implement eCall in new cars by 2018, therefore fulfilling one connected car application, which should pave the way for others to become mandatory in the future.

5.4.2.1 In-vehicle units

The automotive industry has been actively involved in many European and international research projects and consortiums and is increasingly looking to bring cooperative systems and their proposed benefits to private vehicle users. Most modern cars have some form of in car display and
wireless/cellular capability independent of personal devices such as smart phones which is typically
described as ‘connected’. However the next evolution of these technologies will enable them to
communicate with other vehicles and with road infrastructure.

Many state of the art systems have been trialled by luxury car makers in conjunction with leading
infrastructure and traffic control companies as a way of improving safety and reducing delays.
Currently many of these examples are in an urban setting, and many innovative uses of cooperative
systems focus on the interaction between vehicles and intersection infrastructure. A key example is
green time or speed advise systems which provide the driver with the time left on (or until) green
and advise on approach speed which will result in arriving at the signals on a green signal. A
selection of examples of the types of pre-commercial cooperative systems developed in partnership
with OEMs is included below:

- SWARCO have worked on a system which displayed to a vehicle approaching an intersection:
  the turning movements allowed at the junction; the optimised approach speed for a green
  signal; or the time to green if arriving on a red. This work was in Verona and was an
  extension of the work SWARCO-mizar undertook as part of the Compass4D project which
  fitted public transport vehicles and local government fleet vehicles with short range wireless
  ETSI G5 compliant in-vehicle units which communicated with 25 cooperative roadside units
  (Alcaraz, 2014). Additionally vehicles belonging to members of the public were fitted with
  LTE cellular systems. These systems cooperated via a backend with the OMNIA and UTOPIA
  systems. This system engaged in two way communication with the traffic management
  systems and proposed benefits of the feedback data from the in car units are trip times,
  congestion indications and the optimisation of traffic signal timings.

- SWARCO also worked with Audi in Verona to trial speed advisory cooperative systems with
  in-car units in Audi vehicles. The wireless communication between the vehicle and
  infrastructure used both UMTS and LTE mobile communication standards and the European
  ETSI ITS G5 standard (based on IEEE 802.11p).

- Audi have also tested very similar cooperative systems as part of their earlier ‘travolution’
  project which through providing advice on approach speeds have claimed reduced waiting at
  traffic signals and consequently saved on exhaust emissions.

- Similarly car manufacturer BMW have worked as part of the pre-DRIVE C2X project
  (alongside Audi and other manufacturers) to provide a very similar system which advises
  drivers on optimised approach speeds to arrive on green (Schulze, et al., 2010).

5.4.2.2 Roadside infrastructure units

Two-way wireless communication (in the 5.9 GHz spectrum) common in C-ITS projects, and this
standardised method of facilitating cooperative systems has been adopted by many infrastructure
and equipment manufacturers as a basis for their systems and has started to enter the retail market.
Prominent examples include Siemens Sitrack C940ES WLAN controller which complies with
IEEE.802.11p (Siemens, 2013), and several units produced by Kapsch; the TRX-9450 and MTX-9450
transceivers which are designed to communicate with in-vehicle units (Kapsch). Siemens also claim
that their wireless ‘Scalance’ communication modules can transmit data to in-car units (Siemens,
2013).

Other large infrastructure manufacturers such as Denso and Dynniq (formally Imtech) have also
been heavily involved in the development of proof of concept cooperative systems as part of larger
consortiums or research projects. Several pre-market products have been tested by different
manufacturers.
Dynniq (formerly Imtech) have had a large involvement with several European projects, notably FRIELOT (Jeftic, 2012) and SAFESPOT (Tona, 2013) as a result of their experience with these types of project, and as a direct result of involvement in FRIELOT Imtech advertised in 2011 the first commercially available C-ITS platform (Imtech, 2014), which was announced during Verkeer & Mobiliteit 2011 as acknowledged by the final report of the FRIELOT project (Jeftic, 2012). Information from Imtech Traffic and Infra’s website indicates that the system utilises both in vehicle and roadside units using the wireless standards based on IEEE 802.11p all managed via a web application (Imtech, 2014).

Another interesting offering from Imtech Traffic & Infra is the Imflow traffic management system which adaptively balances traffic flows including managing policy requirements, vehicle priority and traffic signals. Of interest here is the proposed compatibility with cooperative systems claimed by Imtech (Casteleijn, 2012). The extent of this compatibility and its application is less clear.

Denso Corporation (headquartered in Japan) have taken an active role in cooperative systems research across the world including ‘testbeds’ in the USA, EU, China and Japan including work in ‘DRIVE C2X project’ and the car2car consortium. Denso are working towards commercial deployment of both integrated cooperative units and retrofitted units for vehicles. Denso are involved with the Thai government, with whom they have signed a memorandum of understanding, to supply cooperative systems’ infrastructure to allow reduction of CO₂ emissions (Denso, 2014).

For further reading on various types of both in-vehicle and roadside units used in cooperative systems the PRE-DRIVE C2X final report contains a detailed discussion of various units and systems supplied by a multitude of industry partners (too many to discuss within the scope of this review) including partners in the vehicle and infrastructure industry (Schulze, et al., 2010).

5.4.2.3 Cooperative systems projects in Europe

Here we have included a list of European projects which have trialled and demonstrated what is likely to become the foundation of large-scale C-ITS projects.

**A2/M2 Connected Corridor (ongoing)** - A partnership between Highways England, Department for Transport, Transport for London and Kent County Council, looking at the stretch of road between the Dartford crossing and the Port of Dover. Two feasibility studies are being undertaken (due to complete at the end of June 2016) looking at connectivity and data and services. A track trial is due to be undertaken in early May 2016. The corridor is expected to implement floating vehicle data (FVD), road-works warnings, in-vehicle signage and green time optimal speed advisory services in its first phase. The overall programme has been included in a bid for EU funding and is called INTERCOR and is a linked corridor between Paris, Rotterdam, Calais and London.

**NordicWay (ongoing)** - A series of cooperative corridors for road traffic in Finland, Sweden, Norway and Denmark. These field trials aim to be the first large scale tests of C-ITS using cellular communications (3G and LTE) to disseminate information about obstacles on the road, weather conditions, slippery surfaces and accidents through a common architecture.

The stated goal is to “lay the foundation for automated cloud communication via cellular networks with data generated by vehicle on-board sensors and the surrounding infrastructure”. The project also aims to develop a business model and a strategy for roll-out of cellular based C-ITS services (FOT-NET, 2015).

**C-ITS corridor (ongoing)** - The Cooperative ITS Corridor project is currently in a pre-deployment phase and will be trialled on roads in The Netherlands, Germany and Austria. The project involves European road operators, urban authorities, the automotive industry and the Car 2 Car Communication Consortium implementing C-ITS services across international borders. Initially the
services will be road works warning and probe vehicle data. Communication from the vehicles and the infrastructure uses ETSI G5 standard wireless communication and cellular networks (3G and 4G/LTE) (ERTICO, 2015).

**SCOOP@F (ongoing)** - The French national C-ITS pilot is being carried out by a partnership which includes government, road operators and the automotive industry at five test sites including urban and inter-urban roads (Direction Général des Infrastructures des Transports et de la Mer, 2014). The services being tested are Intelligent Speed Adaptation (ISA), hazardous location warning, road works warning, in-vehicle signage, traffic jam ahead/congestion warning, intersection safety, stationary vehicle warning, vulnerable road user protection and emergency vehicle warning. Communications are by ITS-G5 and cellular networks.

**COLOMBO (2016)** - COLOMBO is another recently ended European project which looked to address the issue of penetration rates of cooperative systems. The project considered the initial stages of V2X communications roll out when a small percentage of the vehicle fleet will have cooperative capability. The final report, published in early 2016, outlines a variety of methods to use the data from cooperative vehicles even when the penetration rates are very low. For instance COLOMBO combined data from cooperative vehicles and traditional loop detectors to provide more robust modelling of emissions from vehicles.

A custom self-organizing traffic control algorithm (SWARM) was devised by the University of Bologna which used data from cooperative vehicles to control traffic in an urban environment. The project found that even if only 1% of the fleet was fully equipped with V2X communication systems then SWARM could perform as well as or better than traditional adaptive traffic control with relies on loop detectors

**Compass 4D (2015)** - Compass 4D is a recently ended European project which aimed to provide: red light violation warning at intersections; road hazard warnings to drivers; and energy efficient intersections (Vreeswijk & Koenders, 2013).

The project built on the work in FREILOT and COSMO projects and utilised ‘pre-commercial’ equipment. The project also used ETSI G5 for 5GHz wireless communication and uses the ETSI TC ITS protocol for 3G/LTE cellular systems. In the Verona test site SWARCO provided 25-pre market roadside units which complied with ETSI G5 as well as trialling the first ETSI compliant LTE cellular communications (Vreeswijk & Koenders, 2013).

**COBRA (2013)** - The COoperative Benefits for Road Authorities study (COBRA) investigated the benefits and costs of deploying cooperative systems as a decision support tool for Road Authorities. The project categorised all C-ITS systems into three bundles: safety, traffic efficiency and environmental impact. The project developed costs of deployment and a business plan for these bundles. The project considered two technology platforms for deployment of the bundles of cooperative systems: cellular and wireless beacons. This assessment was thorough and examined every major cooperative-ITS project and their benefits and costs (Mocanu, 2014).

**eCoMove (2013)** - ‘eCoMove’ was a European project which aimed to reduce carbon dioxide and other vehicular emissions in addition to increasing fuel economy via the use of cooperative systems. Of particular interest is sub-project 5 ‘ecoTraffic Management & Control’, led by Imtech (Katwijk & Vreeswijk, 2010). eCoMove used various platforms for its cooperative systems including those developed in CVIS, DRIVE C2X and FREILOT (Zhang et al., 2011).

**COSMO (2013)** - The COSMO projects stated aims are to build on projects such as CVIS, SAFE SPOT and COOPERS (covered below) to deploy cooperative systems for extended trials in a real road environment (COSMO, 2011).
Three test sites are used in Salerno (Italy), Vienna (Austria) and Gothenburg (Sweden). The Salerno and Vienna field tests use cooperative systems to highlight road works, improve safety, control access and encourage eco driving. The Gothenburg trial utilises cooperative systems at signalised junctions to provide information to buses regarding approach speed to ensure arrival on a green signal as well as the current speed limit (Swedish speed limits are varied dependent on congestion). The COSMO project makes use of 802.11p wireless and 3G communication, these technologies are based on technology advanced under the CVIS and SAFESPOT projects (COSMO, 2011)\(^{20}\).

**FREILOT (2011)** - This EU funded project utilised two way communication between freight vehicles and local infrastructure to prioritise freight traffic and reduce stop-start driving. The systems were tested in Bilbao, Helmond, Lyon and Krakow. Information about the vehicles speed and location are sent to the infrastructure and speed advice and traffic signal state is relayed back to the driver in turn (Jeftic, 2012)\(^{39}\). While FREILOT did use GPS data for coordinating priority for freight vehicles, 802.11p wireless communications were extensively used for cooperative communication. The FREILOT project utilised off the shelf 802.11a radio cards which were successfully adapted to operate in 802.11p. The onboard partners to these roadside units were android based and mounted on the dashboard (Koender & Turksma, 2011)\(^{45}\).

**CVIS (2010)** - Cooperative Vehicle-Infrastructure Systems (CVIS) was a large European project started in 2006 which aimed to create a unified technical solution for two way communication; develop an open application framework; validate open architecture and system concepts for various applications and to address issues such as privacy, interoperability, policy needs and risk liability (Tona, 2013)\(^{76}\). The first years of the project were focused on developing and standardising the overarching system architecture for CVIS technology; the system was based on IPv6 to allow for the multiple IP addresses per vehicle that may be required for different systems (Kompfner, 2010) (a)\(^{46}\).

Physical media for communication was standardised via the CALM ISO. Different methods of communication were validated; including mobile cellular (2/3G), wireless (CALM M5 incorporating IEEE 802.11p) and infrared (Zhang et al., 2011)\(^{90}\). As part of the overall standardisation objective the sub-project ‘Framework for Open Application Management’ (FOAM) project aimed to produce an open software platform to ensure interoperability, as part of this sub project a developer’s kit (SDK) was developed (Kompfner, 2010) (b)\(^{47}\).

**SAFESPOT (2010)** - SAFESPOT was a European project which aimed to increase road user safety and enhance environmental perception via cooperative vehicle to infrastructure systems. The project operated principally from a safety point of view and helped to provide a baseline exploration of various communications methods and their suitability as an open platform; of particular interest in this is subproject 2: INFRASENS (Spence, 2009)\(^{69}\). This sub-project aimed to develop a platform for C-ITS services from in vehicle and roadside hardware and to data processing and interfacing. The roadside units used in this project utilised 802.11p wireless modules (Spence, 2009)\(^{59}\).

**COOPERS (2010)** - CO-Operative SystEms for Intelligent Road Safety (COOPERS) was a European funded project. Similarly to SAFESPOT the projects aim was to develop and standardise cooperative systems to facilitate an increase in road safety and also enable cooperative traffic management. The COOPERS project tested several different technologies for two way vehicle-to-infrastructure communication, including the TPEG message formats. The COOPERS final report contains a detailed discussion of the business case for a system roll out (Bankosegger & Fuchs, 2010)\(^{5}\).

**DRIVE C2X (2010)** - The Drive C2X project carried out assessments of cooperative systems in field tests across Europe with an aim to verify their benefits and provide a basis for market
rather than focus on one particular application of C-ITS. DRIVEC2X provided a unified testing platform to evaluate the large number of emergent cooperative systems (Mäkinen et al., 2011)\(^6\) which tested various cooperative systems technologies and applications including detailed testing of 802.11p wireless technology and the assessment of commercial products which enable two-way communication between road users and infrastructure. The PRE-DRIVEC2X final report contains detailed analysis of multiple in car and roadside units (Schulze, et al., 2010)\(^6\).

5.4.2.4 International cooperative systems’ projects

**USDOT’s Connected Vehicle Pilots (United States)** - The United States (US) Department of Transport has committed to $42 million of spending on pilots for connected vehicle technologies across the United States. This spending part of a longer term $4 billion pledge for connected vehicles research and development. The project is due to run for three years and has trial sites in New York City, Tampa, and Wyoming. These trials are at the preliminary design phase but also represent a large leap forward for connected vehicles and cooperative systems in the US.

**AERIS (United States)** - The ‘Applications for the Environment: Real-Time Information Synthesis’ (AERIS) project aims to generate real-time traffic data to be used to both support and facilitate green driving. The project utilises in-vehicle units and roadside units which can use the DSRC radio frequencies as well as the IEEE 802.11p wireless standard; messages passed between the infrastructure and vehicle adhere to SAE J2735 which is designed to be fully compatible with 802.11p/DSRC (Schneeberger et al, 2013)\(^6\).

**Vehicle-to-Infrastructures, V2I, Communications for Safety (United States)** - A US Department of Transportation research project that aims to use cooperative systems to exchange information between roadside and in vehicle units with an aim to improve driver safety. This project contributed to the development of open standards such as SAE J2735 and a standardised 5.9GHz radio platform (Dopart, 2014)\(^2\).

**Real-Time Data Capture and Management (United States)** - This US Department of Transportation project uses cooperative systems to capture information to feed into traffic management systems. The overall research aims were to understand the role of DSRC for transport applications, how to utilise data supplied by vehicles equipped with such systems and how to process this data and integrate it into various traffic management systems. The project is ongoing with trials across several US test beds where V2I and V2V infrastructure systems are available (Thompson, 2014)\(^7\).

**ITS Spot Service (Japan)** - The ITS Spot service was begun in Japan in 2011 and covers a large amount of the Japanese road network (Nishio, 2012)\(^5\). The SPOT service is compatible with Electronic Toll Collection systems (ETC) in vehicle units and infrastructure, by the end of 2011 there were 34.24 million ETC equipped vehicles on Japanese roads (Nishio, 2012)\(^5\). While the ITS Spots system provides the user of warning of congestion and potential accidents etc. it also collects probe data from users; including speed, location, and time. This information is passed to road administrators to aid policy making. The system uses 5.8GHz DSRC and claims that as much as 86.2% of Japanese cars on expressways have a unit that can communicate in this way thanks to the compatibility with the ETC system (Nishio, 2012)\(^5\).
6 WP5000: Summary and Recommendations

6.1 Purpose
Sections 2 to 5 of this report describe the algorithms used by Highways England, the algorithms used worldwide, plus research that has been carried out into traffic algorithms. This section discusses the differences between the various algorithms, assesses the functionality and effectiveness of the Highways England algorithms, and makes recommendations for possible enhancements to the algorithms.

6.2 Algorithm Comparison
There are two Highways England algorithms in operation on the motorway network: QP and CM. The algorithms use similar input data (i.e. traffic flows and speeds), but run entirely independently. QP is a reactive algorithm, setting signals in response to slow-moving traffic to warn drivers of queues ahead. CM is primarily a proactive algorithm, using flow data to predict when capacity is about to be reached, and to manage traffic to reduce the occurrences of flow breakdown.

6.2.1 Queue Protection
During the algorithm review process, several types of algorithm have been identified that detect incidents and/or queues. They are given similar names, e.g. queue protection, queue detection and incident detection, but can have very different functionality and purpose.

QP systems are safety systems. They detect slow-moving traffic and set signals upstream of the queues to warn drivers of the queue ahead and to protect the backs of the queues. In a typical QP system, signals are set automatically, although sometimes an operator has to provide confirmation before signals can be set. QP systems look solely for slow traffic, they do not try to determine the cause of the queueing.

Incident detection systems perform a different function. They are primarily a network management tool. They compare speeds and flows at a site, and also at upstream and downstream sites, to try to determine whether there is congestion, and if so, whether the congestion is due to an incident or whether it is due to weight of traffic (recurrent congestion). A typical incident detection system will trigger an alarm in a control centre, and then an operator will deal with the incident. This will involve organising emergency services, incident clearance etc. It might also involve setting of signals and/or warning messages, but these are generally set manually as part of the network management function.

Incident detection systems are complex, as they are looking for traffic patterns at a number of locations. An example of an incident detection system is the one used in Ireland. They have three separate algorithms running concurrently to detect congestion and incidents. The results from the algorithms are combined and if the consensus is an incident, an alarm is sent to an operator. No signals are set automatically.

Most of the research being carried out worldwide is into incident detection, and how the performance can be improved. Currently, the Detection Rate for incident detection systems is 80% - 85%, and the Speed of Detection is 2-4 minutes. Queue detection systems are looking for different things, and are not trying to add intelligence to the outputs. The current Highways England algorithm has a Detection Rate close to 100%, and a Speed of Detection of less than a minute. If a queue forms near a detector, an alert can be raised within 6 seconds.
False Alarm Rates between incident detection and QP systems are not directly comparable. False Alarm Rates for incident detection systems are easy to quantify. These systems generate an alert if their internal intelligence determines that an incident has taken place (as opposed to regular queueing). There will only be a few of these per day, and it can easily be determined whether there actually was an incident. The problem with queue detection systems is defining what the false alarm rate is. For example, a real queue will generate hundreds of alerts, and a spurious alert only one. If there is one of each, is that a false alarm rate of 50% or 0.1%? A further definition that has been used is to calculate the number of vehicles that pass a detector, and determine for each one whether the queue alert (or not) was correct for that vehicle.

The majority of systems in use in other countries are incident detection systems. There are a few QP systems, but these are not as responsive as the English HIOCC system. For example, Denmark uses a QP system based on smoothed average speed, similar to the English CM system.

There are a few combined queue/incident systems, e.g. tunnel warning systems. These are typically camera-based, and look for stationary vehicles. Alerts from these systems are primarily used to inform an operator of a problem, so that it can be dealt with manually.

6.2.2 Congestion Management

There are few CM systems in use in other countries. The Netherlands has a system broadly comparable to the Highways England system, with variable speed limits and dynamic use of extra lanes during congestion (called peak lanes or plus lanes).

The CM systems that are in use in other countries are often less sophisticated than the English CM system, and can be based primarily on fixed time plans (although these can vary according to the day type). Several of the systems are based on providing information to the drivers, e.g. on travel times and weather, and leaving the drivers to make their own decisions. A few countries operate a demand management system based on ramp metering, with algorithms that coordinate the slip road signalling at consecutive junctions, to manage traffic joining the motorway.

6.3 QP system

This section discusses the functionality of the Highways England QP algorithm, its operating characteristics and possible enhancements that could be made to the algorithm.

6.3.1 Functionality

The QP algorithm was developed in the 1970s to be a rapid response system, with the primary objective of improving safety. Decisions that were made at the time regarding the functionality of the system were based on making the roads as safe as possible, by providing warnings at the earliest available opportunity, without performing any additional checks on the extent of the potential queue.

The principle of the QP system is that it reacts immediately to a single slow-moving vehicle, whatever the time of day and whatever the underlying traffic conditions. It would have been possible to build in additional checks to the functionality, but this would have delayed the setting of signals and potentially leave queueing traffic unprotected. Queues during peak periods would have passed the additional checks quite quickly (usually within a minute), so any delay in setting signals would not have been great, but would still have increased the risk, as flows of 100 veh/min would mean that 100 drivers would have not have been warned of the queue ahead.
However, the main reason for not introducing checks was that an accident could occur in the early hours of the morning. MIDAS is not as effective in low levels of traffic flow, as queues are slower to form. Additional checks might have taken several minutes to resolve. During this time, any stationary vehicle(s) would have been unprotected.

The primary benefit of the QP system is an improvement in safety, due to targeted warnings of queues ahead. These warnings apply during both peak and off-peak conditions. Off-peak queues are likely to be caused by incidents; peak queues could be incidents, recurrent congestion, or an incident within existing congestion. Regular drivers on a route might be able to anticipate queues at certain times of the day, but the extent of the queues can change, and there are always irregular users on the road. Therefore, the QP system operates the same way throughout the day, and whatever the flow levels.

The safety benefits of QP have been assessed in a number of studies. The most recent\(^2\) has shown that QP provides a 13% reduction in injury accidents, due to targeted warnings of queues ahead. In addition, applying Smart Motorways infrastructure and signalling provides a 15% reduction in injury accidents, due to smoothing of traffic flows, and the application of mandatory speed limits to the QP system. These benefits are cumulative.

The study relies on large quantities of data, as there are relatively few injury accidents, and general trends can be confounded by external influences and improvements in car safety. Therefore, the contribution of various scheme elements to safety is not known. However, previous work on modifying signalling for the proposed Basic (Rural) Controlled Motorways concept has produced a subjective assessment of where safety benefits arise. Table 9 shows an estimated breakdown of the safety benefits under various traffic conditions.

**Table 9: Estimated accident savings**

<table>
<thead>
<tr>
<th>Traffic conditions</th>
<th>Off-peak</th>
<th>Congested</th>
<th>Incident</th>
<th>Congested + Incident</th>
<th>Accident Saving (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of safety benefit</td>
<td>Primary accidents</td>
<td>Primary accidents</td>
<td>Secondary accidents</td>
<td>Primary and secondary accidents</td>
<td></td>
</tr>
<tr>
<td>QP signalling</td>
<td>No benefit</td>
<td>No benefit</td>
<td>Protects unexpected queues</td>
<td>Protects queues in congested conditions</td>
<td>13</td>
</tr>
<tr>
<td>Controlled Motorways (including QP)</td>
<td>Benefit due to changes in driving environment</td>
<td>Smooths traffic flow</td>
<td>Protection is enhanced by mandatory speed restrictions</td>
<td>Smooths traffic flow, enhances queue protection and provides explanatory messages</td>
<td>28</td>
</tr>
</tbody>
</table>

Any modification to the QP system that delays the setting of signals or reduces the Detection Rate, will adversely impact the above safety benefits to some extent.

Against that, if the signalling displayed to drivers is often inappropriate, drivers will eventually stop believing the information they are being given and some safety benefits are likely to be lost.

6.3.2 Operating Characteristics

The current QP signalling works well when there are clearly defined queues. The system tracks the backs of the queues, setting signals as required in a timely fashion, and clearing the signals when the queues dissipate. The signals remain on within queueing conditions, for two main reasons:

- In the early days of Controlled Motorways, signals were displayed as traffic slowed, then went through the switch-off sequence (50, then 60, then \( \odot \)) when traffic was very slow-moving. Feedback from drivers was that they wanted the signals to remain on at the lowest speed limit used (currently, this is 40mph).
- In stop-start driving conditions, it is necessary for both safety and congestion management to have traffic controlled as it moves between shockwaves. Allowing traffic to speed up when it is going to have to slow again increases the risk of shunts and of excessive braking, leading to additional flow breakdown. Therefore, if signals were switched off as drivers came to a halt, they would need to be switched on again as drivers started to accelerate. This would also be unpopular.

The QP signalling responds quickly to any slow-moving vehicles, in case there is a safety hazard. This can result in situations where, with the benefit of hindsight, signals were not needed. Historically, this has occurred for one of three reasons:

- A sensor fault. One individual high occupancy reading will result in signals being set. A “blip” on a sensor, for whatever reason, will lead to signals being set for 4 minutes.
- An individual slow-moving vehicle. If a vehicle travels very slowly past a detector, this will also trigger signalling that lasts for 4 minutes. The system is responding to a real event on the road, such as a vehicle pulling onto or off the hard shoulder, or slowing at a junction to decide whether to exit. The vehicle is a hazard, but its presence is only fleeting.
- A very long vehicle. Occupancy is a combination of speed and vehicle length. Cars will only trigger queue protection signalling at speeds below 10mph, but lorries can trigger alerts at speeds of 25mph, or even higher for very long vehicles.

Sensor faults are currently mitigated by known faulty sensors being disabled for queue protection until they can be repaired. For loops, this is typically a connector issue, not requiring lane closures to repair, but sometimes loop recuts are required. The downside of disabling loops is that real queues at that location will not be protected as effectively.

Regarding individual slow-moving vehicles, a policy decision was made when HIOCC was first implemented that all such alerts would set signalling. To do otherwise would run the risk of signals not coming on to protect a crashed/broken down car in the early hours of the morning, when flows are low.

Long vehicles setting signals has been addressed by HIOCC2. The Watchdog function within HIOCC2 checks speed as well as occupancy, and suppresses alerts from higher speed vehicles. The only time a long vehicle will still cause signals to be set is when speed data is not available at a site.

Signal setting rules have been developed that strike a balance between signals that are appropriate to the traffic conditions, and that do not frequently change. For QP signalling, the overriding consideration is safety, so signals are allowed to switch on at any time if required. Other than that, the principles are:

- Once a signal is on, it has to remain on for 4 minutes, to avoid rapidly changing signals.
- When travelling between shockwaves, drivers are permitted to travel at 50mph, then are slowed to 40mph as they approach the next shockwave. This is appropriate whatever the
signal spacing. However, on the M42 which has closely spaced gantries, the variability is suppressed by signals all remaining at 40mph within shockwaves. This improves the driver experience, while increasing delay slightly.

6.3.3 Potential Enhancements

There are three main areas where possible enhancements to the QP system could occur:

- Changes to the input data used by the algorithm.
- Changes to the processing algorithm itself.
- Changes to the way information and/or instruction is communicated to the drivers.

6.3.3.1 Input data

The quality of potential input data has improved markedly since the HIOCC algorithm was developed in the 1970s. At that time, speed data was often not available, and so occupancy was used as a proxy. This introduced additional variability to the algorithm, as vehicle length then became a factor.

Speed data is now far more reliable, so it should be possible to run the QP algorithm from speed data. This would improve accuracy, and would also allow a greater flexibility within the algorithm to use speeds from more than one vehicle to determine whether a queue had formed that needed protecting.

The downside of using speed data within the algorithm is that there might need to be a backup in case speed data was not available (due to one loop of a pair being faulty). The system might be able to revert to occupancy. Alternatively, there might be sufficient speed data from adjacent lanes for a speed algorithm to work effectively. Work could be carried out to determine how often speed data fails and to quantify the potential effect on the signalling of such a failure.

The increasing use of radars as detectors (instead of inductive loops) should result in greater availability of speed data.

Ultimately, the input data for the QP algorithm could come from in-car units. These would be able to supply speed data from every location on the network, rather than only from detector locations. This would improve the speed of detection of queueing traffic, especially late at night when the flows are low and queues can take several minutes to be detected by a sensor.

A reliable means of communication from the in-car units to the algorithm would need to be developed. The system would rely on a sufficient number of equipped vehicles on the road to provide continuous speed data.

6.3.3.2 Processing algorithm

The current HIOCC algorithm is rapid response, with a single alert being sufficient to set signals. This provides the greatest safety benefit, but can result in signals being set inappropriately. The algorithm could be modified so that it performs additional checks before it sets signals. Examples of additional checks would be:

- Only set signals if two alerts (or a higher predetermined number) are received from the same lane. This might reduce the amount of signalling due to a single slow-moving vehicle, but would still be susceptible to false alerts due to a faulty sensor.
• Only set signals if alerts are received from two lanes. This might reduce the amount of signalling due to a single slow-moving vehicle, and could also reduce the signalling due to faulty sensors (assuming that other lanes are working correctly).

• Only set signals if alerts are received from two consecutive sites. This would ensure that signals are only set for queues of at least 500m, and would reduce the False Alarm Rate significantly. However, there would be delays in setting signals of at least 90 seconds while the queues built up, and queues overnight might remain unprotected for a lot longer.

All of these enhancements would slow the Speed of Detection, so would potentially have adverse safely impacts. However, the first two options would only add a few seconds to the time to set signals, and the benefits from more appropriate signalling might outweigh the slightly reduced safety. The third option would produce very few false settings, but would have a far greater effect on safety.

When HIOCC2 was being developed, various additional checks were considered. However, the only one implemented was a “Watchdog” check on the speed of the individual vehicle that generated a HIOCC alert. The potential effects of further additional checks could be investigated in a separate piece of work. Real traffic data could be used to simulate the alerts, the checks and the resulting signal settings. Individual vehicle data would be required, as the 1-minute average data currently logged does not have sufficient detail to identify individual vehicle speeds and the alerts that would be generated.

Another way the algorithm could be modified is to make use of average speed data directly, rather than individual occupancies. This would require speed data to be the main input (see Section 6.3.3.1). The algorithm would then be able to calculate average speeds (within a lane, or at a site), and then set signals accordingly. The average speeds could be raw or smoothed, and could be calculated at shorter intervals than the 1-minute period used by the CM algorithm. Using average speeds would increase the reliability of the signal settings, but would delay the setting of the signals. Work could be carried out to determine the impacts of various speed-based settings, both on reliability and safety.

At the extreme end of the spectrum, one solution could be to scrap the QP algorithm completely, and to use the smoothed speed function within the CM algorithm to set the signals in the event of a queue. This solution would be the simplest, and the CM algorithm could be modified to set 40mph signals in response to slow speeds (as it does currently in the West Midlands). However, using smoothed speeds would mean that signals would switch on about 5 minutes after a queue formed (depending on the severity of the queueing). During that time the queue would be unprotected.

The QP system in Denmark uses this functionality.

### 6.3.3.3 Output of information

Once an alert is generated, it can be communicated to drivers in a number of ways. The current system uses speed limits (mandatory at SM locations, advisory elsewhere), and there are a number of signal setting rules to determine what signalling is set.

There are a number of options that could be implemented that could improve driver satisfaction and/or reduce delay. Some are likely to have an adverse impact on safety, as the current system ensures that signalling is set whenever possible in the vicinity of queueing traffic, and the identified options generally reduce the amount of signalling.

Four examples of changes to output information are:

• Reduce the minimum on time from 4 minutes to 2 minutes.
• Switch signals off in queues.
• Use messages and/or pictograms to convey queue protection information.
• Provide information directly to in-car units.

These are discussed in greater detail below.

Reduce the minimum on time

To reduce the amount of signal variability, both QP and CM signalling have a minimum on time and a minimum off time of 4 minutes, meaning that once a signal has changed state, it cannot change back again for 4 minutes. There is an exception for QP signalling, in that as it is a safety system, signals can come back on whenever required.

Having a minimum on time of 4 minutes for QP means that when an off-peak alert is generated, the associated signals have to remain on for at least 4 minutes. If the alert was a one-off, caused by a single slow vehicle, a long vehicle or a sensor fault, then the signalling would not have been necessary and could have been switched off earlier. Switching the signals off earlier would reduce the number of drivers affected by the unnecessary signalling, which would improve driver satisfaction and also reduce the delay caused by the signalling.

The minimum on time is a configurable parameter within the QP algorithm. It can easily be changed within site data, and no outstation visits should be required. A change to 2 minutes would halve the number of drivers affected, while still maintaining consistency of signalling for temporary slowing of traffic.

It is possible that a change to the minimum on time could result in greater signal variability during shockwave conditions. In a SM environment, it is likely that the combination of lead-in signalling for queues further downstream and the CM flow/speed settings would keep signalling on throughout, but work could be carried out to determine if there are likely to be any side-effects of reducing the minimum on time for QP to 2 minutes.

Switch signals off in queues

Drivers have reported dissatisfaction from sitting in queues with 40mph limits being displayed, as they think that a speed limit should be achievable. Signals could be switched off in queueing conditions, and messages used to inform drivers of any delays.

This could be a viable option in a queue for a lane closure. Traffic is likely to travel slowly up to the bottleneck, and then be released once it had passed through. All that would be required would be a roundel downstream of the bottleneck to cancel the previously displayed 40mph signal.

However, there would be a drawback in stop-start driving conditions. When drivers started to speed up, it would be necessary to switch the signals back on, both for safety reasons (traffic would be approaching a further queue) and for congestion management reasons (to avoid excessive braking that would cause additional shockwaves). This would be likely to be unpopular with drivers. The alternative of leaving the signals off as drivers accelerated would have an adverse impact on safety and delay.

The current queue protection system does not distinguish between causes of queueing. To add additional intelligence to cater for various queueing behaviours (e.g. queueing or stop-start driving) is likely to be prohibitively expensive, especially as it would provide no economic benefit, either to safety or delay.
Use messages and/or pictograms

The QP system currently sets speed restrictions. In SM environments, the QP signalling is mandatory, and is generally well observed. The drawback of this is that when there are false alerts, traffic is slowed unnecessarily, causing delay and driver irritation.

An alternative would be to use messages and pictograms for queue protection, and only use mandatory speed restrictions for congestion management. This would mean few speed limits set during off-peak periods (only by operators in response to on-road events).

The main objective of queue protection (to warn drivers of queues ahead) would still be achieved. Drivers would have heightened awareness of potential problems ahead. However, this option would be likely to lose some of the safety benefits of QP within a SM environment, as traffic speeds are likely to be higher and therefore the risk of secondary accidents greater. Heightened driver awareness might compensate for this, but this is an unknown factor.

Provide information directly to in-car units

In the future, in-car cooperative vehicle technology will be capable of receiving speed limit information. This could be provided to the driver, or the in-car systems could limit the car speed to the prevailing speed limit. This could be additional to, or eventually replace, the physically displayed variable speed limit.

This would be a more efficient way of communicating speed limit information, but would not address the suitability of the speed limits. In addition, systems that restricted cars to the speed limit would need a high proportion of equipped vehicles, to reduce risk of conflicts with non-controlled vehicles.

6.3.3.4 Education

Although it is not an actual enhancement of the algorithm, there are several features of the algorithm that are often misunderstood by the public, and which can therefore lead to driver dissatisfaction. Educating the public for the reasons behind the QP (and CM) settings would be likely to lead to greater driver acceptance of the signalling.

The two main areas where drivers have misconceptions are:

- That the signalling is set without regard to current traffic conditions. Some drivers believe that signals are set by operators, and possibly even to a fixed time plan. These drivers are more likely to feel that the signals are potentially inappropriate. Educating the drivers that the signals are reacting to actual traffic conditions could improve driver acceptance of the signalling.

- That the 40mph signals are causing congestion. Many drivers have realised that 40mph signals are followed by an area of congestion. Several of these drivers believe that the signals are causing the congestion, rather than reacting to existing congestion. They have suggested that 40s should not be used. Again, educating drivers about the cause/effect cycle of congestion and signalling could improve driver acceptance of the signalling.

6.4 CM algorithm

This section discusses the functionality of the Highways England CM algorithm, its operating characteristics and possible enhancements that could be made to the algorithm.
The CM algorithm was developed in the 1990s to smooth traffic flows as they approach the capacity of the road, thereby delaying the onset of flow breakdown and also aiding recovery from flow breakdown.

Some countries use similar systems that are based on typical times of congestion. They are essentially time-based, but can apply different timings for different day types. The Highways England CM system is not time-related, but uses the actual current flows to set the signals, based on the predicted capacity of the road.

The aim of the CM system is to reduce congestion, and benefits arise from increased safety, reduced delay and improved journey time reliability. The primary economic benefit is from an improvement in safety. Smoothing the traffic flows reduces the chance of accidents, and the changes to the driving environment, including the use of mandatory speed limits, enhances the QP functionality (see Table 9 in Section 6.3.1).

The journey time benefits are maximised by careful calibration of the thresholds. Poorly tuned schemes can cause additional delay by having signals displayed unnecessarily.

The CM algorithm is designed to smooth traffic flow, so is less responsive to changes in traffic conditions than the QP algorithm. Traffic data is smoothed, and there are different thresholds for switching signals on and off, all of which mean that signals do not often change state.

The algorithm predicts when traffic flows are reaching the capacity of the road. The current flows are measured, but the capacity is predicted from historical data. Currently, the capacity value in the algorithm has a single value for each location on the motorway. This does not reflect real life, where capacity can depend on several factors:

- Morning and afternoon capacity can be different, depending on traffic movements.
- Capacity is higher in the summer months compared to the winter.
- Some weekdays might have different capacities to other weekdays, and weekends can be different, due to differing traffic patterns on each day.
- Weather conditions can reduce the capacity.

Capacity can also vary greatly from day to day, in an unpredictable fashion. Various events can trigger flow breakdown during periods of high flow, e.g. HGVs overtaking, in-car distractions or external distractions such as people on overbridges. These events are effectively random.

The CM signal settings are optimised as far as possible to provide signalling that is appropriate to the traffic conditions, but there are often days or peak periods where the signalling is not particularly appropriate, due to the capacity at that time being different to the predicted value.

The primary function of the CM algorithm is to use flow data to set and clear the signalling. There are also speed thresholds within the algorithm that can also set signals, or cause signals to stay on. These speed-related settings are primarily present in case the CM algorithm operates on a road with no queue protection. This was the case in the early days of CM rollout, but nowadays CM is always implemented on roads that already have QP enabled. Therefore, in most cases the signalling at low speeds is controlled by the QP algorithm. CM signalling has been used in the West Midlands to keep 40mph signals on during stop-start driving conditions, and the CM signalling will provide a failsafe setting should HIOCC not operate for any reason. The settings will typically lag behind the QP
settings by about 5 minutes, but would still provide some protection for long-term queueing traffic. This type of setting is used in Denmark for queue protection.

6.4.3 Potential Enhancements

The current CM system has the advantage over fixed time systems as it uses the current flow information to predict when capacity is about to be reached. The drawback of the current system is that the capacity has to be a single value, whereas capacity is continually varying. Predicting the capacity accurately in advance is not possible, due to the random factors associated with flow breakdown, but it is possible to predict capacity trends.

It would be possible to determine a number of likely capacities based on time of day, day of week and seasonality. From these, a different set of thresholds for each capacity could be calculated. At the moment, site data can only contain one set of thresholds, and new site data loads are infrequent (typically every 4-6 months). Therefore, each particular scheme only utilises a single set of thresholds.

It would be possible to apply a change in thresholds for seasonality by having two sets of site data, and swapping them at appropriate times of the year. Shorter-term changes, such as for day of week and time of day, are currently not possible.

The rollout of CHARM from December 2017 onwards should provide additional flexibility to applying thresholds. CHARM will replace the current COBS instation, and will provide additional communication to the outstations, potentially allowing thresholds to be changed on a short-term basis, even to the extent of adjusting thresholds for specific peak periods. Once CHARM is operational, it will be possible during the calibration and optimisation phases of each scheme to calculate a number of different sets of thresholds. Further work would be needed to determine how many different sets would be optimum, but once calculated, the thresholds would then be able to be applied at the roadside.

Highways England has developed a concept paper describing in broad terms how such a scheme might operate.

Initial research by TRL into the effect of weather on capacity has indicated that it is not possible to determine any significant correlation between poor weather and reduced capacity. Random day-to-day variability swamps any differences there might be, and it is also likely that drivers modify their behaviour during bad weather to behave in a smoother fashion, e.g. less lane changing and less severe braking. These factors would potentially compensate for drivers leaving larger headways and travelling slower, and allow capacity to remain relatively unchanged. Because weather does not seem to significantly affect capacity, it is unlikely that any weather-based capacity prediction functionality would be cost-effective.

Also, any real-time capacity prediction model is unlikely to be cost-effective. Typically, the best estimate for capacity is to use the capacity at the same time of day on the previous day of the same day type and this is how the predetermined thresholds would be calculated.

CHARM will enable a broader overview of conditions elsewhere on the network, which could be used to predict the flow levels expected at potential bottlenecks. The control of the CM signalling could be taken from the outstations and placed within the instation (i.e. CHARM). CHARM could also

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3 Concept of Operation: MIDAS Use (Brian Taylor, May 2016) Highways England Report
assist with demand management. However, the underlying issue of not knowing the capacity of the road until flow has already broken down would still exist.

6.5 **Air Quality**

Air quality algorithms aim to reduce vehicle emissions by reducing speeds. This could be a fixed time plan, in response to high flows, or in response to poor air quality.

A flow-based air quality algorithm would be very similar to the CM algorithm, with speed limits being applied at times of high flow (although possibly using lower thresholds). Fixed time plans were considered for two SM schemes, but were rejected following public consultation. Therefore, if an air quality algorithm was to be implemented, it is recommended that it should be related to existing air quality.

It might be possible to develop a system based on localised air quality, but fluctuations in measurements depending on wind speeds etc. might result in variability in speed limits. A more appropriate scheme might be to display speed limits based on projected area-wide forecasts. The use of forecasting and climate modelling as in the DYNAMAX field trials in the Netherlands would eliminate the need for a large emissions sensor network and make the system predictive rather than reactive.

However, all air quality schemes are likely to introduce additional delay.

6.6 **Expressways**

Expressways will be A-roads that will be as well designed as motorways and which will offer the same standard of journey to users. The performance of the QP and CM algorithms on motorways has been reviewed, and consideration given to whether different provision would be beneficial on expressways for:

- Spacing of signals.
- Spacing of detectors.
- Types of detector.
- Algorithm parameters.

The conclusion was that the current motorway provision was optimal, and that there was no particular reason to change any of the above factors.

The definitive design of expressways has not yet been finalised. Consideration might need to be given to intervisibility, or to any features on expressways that differ from motorways. One possibility for differences is the design of junctions. If slip road merge or diverge areas are shorter than on motorways, then consideration might be needed of how to deal with potential slow-moving vehicles.

However, it is anticipated that the algorithms for expressways will require little change from those for motorways.

6.7 **Cooperative Systems**

Connected vehicles make possible the use of the vehicle itself as a sensor for real-time data. It is expected that future vehicles will continually report their position, speed, direction and basic vehicle information on a regular basis, most likely by transmitting this information in a Cooperative Awareness Message (CAM). Collecting this data, normally called FVD or probe vehicle data, gives
traffic managers a real-time view of the state of the network. This allows traffic management strategies to be modified as traffic conditions change. The collection of FVD will be a priority application to be implemented on the A2/M2 connected corridor.

In the medium to long term, it is expected that all new vehicles will be equipped with this capability, and once the equipped vehicle fleet reaches a sufficiently high penetration (say over 90%), this data will provide a quicker, more accurate and more timeous source of traffic data than fixed-location detectors.

Full replacement of physical detection technologies will depend on achieving a very high penetration rate of the associated technologies. However there will be real advantages to using available data from in-car systems to supplement the existing detector network on the UK’s motorways. A key focus of ongoing research is what degree of penetration of connected vehicles is required before FVD can be used to make reliable assumptions about the non-connected fleet. Such work will accelerate the usefulness of FVD in the medium term.

In the United States V2V communication capability is set to become mandatory, with the gradual introduction of V2V capability from 2020 onwards, from here the US DOT estimate that it will take 37 years for full penetration of this technology. In the US the focus is on federally mandated V2V, with V2I following much later on. This is because of legal complexity arising from a federal system; in the UK any push for V2V capability in new cars could be more easily matched by Highways England with V2I systems.

The EU has no set approach to the introduction of V2V and V2I, with a more market driven approach. This likely means that while cooperative systems will appear earlier in Europe, the rate of growth is unlikely to be as fast as in the US if the mandate is implemented. There are ongoing proposals to deliberately advance connected vehicle technology across Europe.

In addition to the vehicle being a sensor in its own right, connectivity also raises the possibility of using the vehicle’s own on-board sensors. CAM messages can contain optional data like the state of the vehicle’s wipers, lights, and other on-board sensors. These can be used to determine the local weather conditions with a high degree of accuracy. Suspension and chassis sensors can be used for road condition monitoring by detecting potholes etc.

The range of vehicle sensors is expected to increase greatly over the coming years, driven both by mandatory requirements (electronic stability controls etc.), and the requirements of increasingly automated vehicles which need a vastly improved awareness of their surroundings than non-automated vehicles. So for example we can expect vehicles to become equipped with 360° video, radar and LIDAR sensors, high-accuracy GNSS location tracking, and the on-board processing required to use the outputs from these sensors to assist the driving task. The timescales for these developments are not yet clear – opinions vary from a few years to a few decades.

6.8 Recommendations

Various options have been identified within this report for improving the algorithms used on the Highways England network. The current combination of QP and CM algorithms perform the same function as they did when they were first introduced over 20 years ago, and there are some opportunities for improvement.

6.8.1 QP algorithm

There are several incident detection algorithms used in other countries, and considerable research is still being carried out into these at various universities. However, these algorithms are used to
detect incidents and inform operators who then organise a coordinated response to the incident. This is primarily a network management aid, so that the operator can inform emergency services, recovery vehicles etc. to manage and clear the incident. Signalling is a secondary concern, and is often limited to strategic messages. The Highways England QP system performs a different function, setting tactical signalling to protect the backs of queues. It not only protects unexpected queues due to incidents, it also sets signals in response to recurrent congestion, which the incident detection systems are designed to filter out.

The introduction of CHARM will provide additional functionality similar to incident detection. It will allow capacity and demand management, prediction of congestion and implementation of diversion strategies. It will also allow operators to inform drivers via strategic messages, journey time information etc. Tools such as a “virtual patrolling” facility will predict the build-up of congestion. However, all of this functionality will be used for strategic management of the network; it will have a far lesser impact in terms of safety, which is the primary purpose of the QP system. Therefore, it is recommended that the QP system should be retained, but with possible modifications.

The performance of the QP system can be evaluated on three main criteria:

- Appropriateness of the signalling. This is a combination of detection rate (are all queues detected?) and false alarm rate (how often are signals set unnecessarily?).
- Variability of the signalling. A system that changes signals rapidly in response to traffic conditions will provide the most appropriate signalling, but previous feedback from drivers is that they prefer to see more consistent signalling.
- Speed of response. The longer a system takes to detect and validate a queue, the longer that queue will be unprotected, increasing the risk of an accident.

There is a trade-off between these elements. For example, an appropriate system will be more variable, and a system that has many cross-checks will have a low false alarm rate but will have a slower speed of response.

The current QP system is designed to be rapid response, with few checks applied. It therefore has a fast speed of response and a very high detection rate, but also a relatively high false alarm rate. The signals are generally responsive to traffic conditions, but a few factors are applied to make the signalling more consistent.

A number of options have been identified that could provide benefits. A full list of options is provided in Appendix F and the main recommended options are described in Table 10, with an indication of which of the criteria the option is designed to improve, and which criteria might be adversely affected.

**Table 10: Recommended Options (Queue Protection)**

<table>
<thead>
<tr>
<th>Option</th>
<th>Benefits</th>
<th>Potential disbenefits</th>
</tr>
</thead>
</table>
| A      | Use speed data rather than occupancy data | • Would improve appropriateness of the settings  
         |                        | • Would allow average speed to be used, further improving appropriateness  
         |                        | • If speed data became unavailable, might result in some queues being detected late or missed altogether  
         |                        | • This could be mitigated by using occupancy as a back-up |
| B      | Carry out additional checks for the presence of a queue | • Would reduce the false alarm rate | • Would slow down the speed of response |
These options could be implemented individually, or in any combination. The additional checks in Option B could be more sophisticated if Option A was implemented. The impact of Option C would be lessened in either or both of Options A and B were implemented, as there would be fewer false alarms.

Option A could be used for both loop and radar data. However, radars provide speed data that is then converted to occupancy (for loops, occupancy comes first). Therefore, for radar data, it would be logical to use speed data within the QP algorithm.

If Option A is to be considered for loop data, then the availability of speed data from loops should be investigated. From this, a risk assessment could be carried out into whether removing an occupancy back-up might result in unprotected queues. Initial investigations suggest that availability of speed data is now extremely high.

Prior to a final decision being made on which option(s) to progress, it is recommended that further work be carried out into the extent of the benefits and dis-benefits of each option. For example, there are several levels of checks that could be carried out within Option B.

The overall objective of all three options is the same: to reduce the disbenefits arising from false alarms, without adversely affecting other parts of the system. If one or more of these options is to be implemented and assessed, then a suitable measure for success would need to be identified. The effect of signalling on safety, delay and driver satisfaction is hard to quantify, so the suggested measure is:

- Number of minutes per week for which unnecessary signalling was displayed.

Fewer false alarms and/or reducing the impact of the false alarms would cause the measure to come down. The measure could be used directly when looking for improvements on a particular scheme or section of road. To compare between schemes, it would be necessary to normalise the measure for distance.

### 6.8.2 CM algorithm

The general principle of flow/speed settings within the CM algorithm works effectively. The thresholds have to be determined in advance, based on a single capacity value. This can at times lead to inappropriate signalling, when the actual capacity is different to the predicted capacity.

The introduction of CHARM will allow greater flexibility, including having several sets of thresholds. The number of sets of thresholds will depend on how many day types are identified. It is recommended that work be carried out to determine how many sets of thresholds would be optimal. In addition, liaison with the CHARM development team will be necessary to ensure that the different sets of thresholds will be able to be applied correctly (either at the outstations or within CHARM). Table 11 summarises this option.

<table>
<thead>
<tr>
<th>Option</th>
<th>Benefits</th>
<th>Potential disbenefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop different sets</td>
<td>- Would improve appropriateness of</td>
<td>- Requires additional work during</td>
</tr>
<tr>
<td>Option</td>
<td>Benefits</td>
<td>Potential disbenefits</td>
</tr>
<tr>
<td>--------</td>
<td>----------</td>
<td>----------------------</td>
</tr>
</tbody>
</table>
| of thresholds for varying capacities | the settings  
• Would increase the journey time benefits from a scheme | the calibration and optimisation phases of a scheme |

In the short term, it might be possible to implement two sets of thresholds, for the summer and winter, by having two sets of site data and swapping them as required. However, the seasonal effects on capacity are generally lower than those for morning/afternoon and different day types, so the benefits would be relatively small.

In the longer term, CHARM may also allow more accurate prediction of flow breakdown. Existing flow levels could be compared against flow levels on other days, and signalling set accordingly. Information on flow breakdown elsewhere on the network might provide a more accurate prediction of capacity. Further research would be needed to determine the viability of such a solution.

6.8.3 Future developments

Once the V2V and V2I types of technologies are widespread and reliable, the richness of traffic management data will increase massively. This means that not only can physical detectors be mostly retired but new algorithms can be developed to take advantage of the large volumes of data on a per car basis. This will allow not only efficiency improvements to existing algorithms but also allow traffic management techniques such as variable speed limits or rerouting to be applied to individual vehicle classes or even individual vehicles. The possibility that traffic management systems could actively control elements of a car (e.g. cruise control) adds an entirely new dimension to traffic management.

In order to achieve this, Highways England will have to consider the following over the next few years:

• Increased investment in data collection and storage.
• Investment in roadside infrastructure.
• Funding for the development of new algorithms to use increased data sources.
• Funding for research into what fleet mixes of connected vehicles can be used to extrapolate useful information about the non-connected fleet.
• Commitment to the security and anonymity of collected information.
• Continued engagement with the wider C-ITS movement in Europe.
• Champion mandatory non-intrusive in-vehicle systems in the UK.

6.8.4 Summary of enhancements

Table 12 summarises the proposed enhancements discussed in this section, and indicates the approximate timescales for their implementation.
**Table 12: Timescales for enhancements**

<table>
<thead>
<tr>
<th>Year</th>
<th>QP</th>
<th>CM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>• Mitigate the effects of false alarms by changing the minimum on time from 4 minutes to 2 minutes</td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>• Use speed data rather than occupancy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Implement additional checks for the presence of a queue</td>
<td></td>
</tr>
<tr>
<td>3-5</td>
<td></td>
<td>• Use CHARM to apply separate thresholds for time of day, day of week etc.</td>
</tr>
<tr>
<td>5-10</td>
<td>• Combine V2V and fixed location speed information to provide more accurate queue and incident detection</td>
<td>• Develop prediction tools within CHARM to better predict flow breakdown and set signals accordingly</td>
</tr>
<tr>
<td></td>
<td>• Provide information direct to cars</td>
<td></td>
</tr>
<tr>
<td>10-20</td>
<td>• Use V2V as main data source</td>
<td>• Develop more sophisticated congestion prediction tools</td>
</tr>
<tr>
<td></td>
<td>• Provide instruction direct to cars</td>
<td>• Consider demand management to reduce flow levels during congested periods</td>
</tr>
</tbody>
</table>
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AID</td>
<td>Automatic Incident Detection</td>
</tr>
<tr>
<td>ALR</td>
<td>All-Lane Running - Conversion of the hard shoulder of a motorway to a running lane, either on a permanent basis or as part of a Managed Motorway</td>
</tr>
<tr>
<td>AMI</td>
<td>Advanced Motorway Indicator</td>
</tr>
<tr>
<td>ANPR</td>
<td>Automatic Number Plate Recognition</td>
</tr>
<tr>
<td>APID</td>
<td>All-Purpose Incident Detection</td>
</tr>
<tr>
<td>APTR</td>
<td>All-Purpose Trunk Road</td>
</tr>
<tr>
<td>Artificial Intelligence</td>
<td>The theory and development of computer systems able to perform tasks normally requiring human intelligence</td>
</tr>
<tr>
<td>Artificial Neural network</td>
<td>Computing system made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs</td>
</tr>
<tr>
<td>Active Traffic Management</td>
<td>A method of increasing peak capacity and smoothing traffic flows on busy major highways by using techniques, such as variable speed limits, hard shoulder running and ramp metering</td>
</tr>
<tr>
<td>ATMS</td>
<td>Advanced Traffic Management System</td>
</tr>
<tr>
<td>Basic Controlled Motorway</td>
<td>A Managed Motorway utilising verge as well as overhead signage</td>
</tr>
<tr>
<td>Bayesian network</td>
<td>Graphical model for reasoning under uncertainty, where the nodes represent variables (discrete or continuous) and arcs represent direct connections between them</td>
</tr>
<tr>
<td>CALM (M5)</td>
<td>Communication Access for Land Mobile - An ISO standard which incorporates a European 5GHz spectrum, regional cooperation with DSRC systems and interconnectivity with cellular networks</td>
</tr>
<tr>
<td>CCATS</td>
<td>Camera and Computer-Aided Traffic Sensor</td>
</tr>
<tr>
<td>C-ITS</td>
<td>Cooperative - Intelligent Transportation Systems; term used to describe technology which allows two way communication between vehicles and the infrastructure (or other vehicles) as part of an overarching transport system</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>CAM</td>
<td>Cooperative Awareness Message - One of the components of the reference architecture defined by ETSI for transmitting geographically aware information with relevant date for other vehicles</td>
</tr>
<tr>
<td>Cooperative systems</td>
<td>Generic name given to a new generation of in-car and roadside communications technology which is made possible by data exchange both inter-vehicle, and between vehicles and the infrastructure</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Congestion Management</td>
<td>A proactive flow-based system to manage traffic at times of high flow</td>
</tr>
<tr>
<td>Connected vehicle</td>
<td>A vehicle that is equipped with wireless communications technology allowing it to communicate with its environment. This phrase can mean vehicles with full cooperative systems capability or more generally those which can access cellular networks</td>
</tr>
<tr>
<td>Connectionism</td>
<td>A set of approaches in the field of artificial intelligence as the emergent processes of interconnected networks of simple units</td>
</tr>
<tr>
<td>CM</td>
<td>Controlled Motorway - A Smart Motorway with multiple lanes, variable speed limits and a hard shoulder for use in emergencies only</td>
</tr>
<tr>
<td>C-VSL</td>
<td>Cooperative Variable Speed Limit - A variable speed limit system which makes use of cooperative systems and additional data they provide</td>
</tr>
<tr>
<td>DENM</td>
<td>ITS facility layer message providing Road Hazard Warning (RHW) related information</td>
</tr>
<tr>
<td>DS theory</td>
<td>Dempster - Shafer theory - A mathematical theory, evidence based on a degree of belief represented by a mathematical object and automatic reasoning techniques in artificial intelligence, which is used to combine evidence to calculate the probability of an event</td>
</tr>
<tr>
<td>Driver location sign</td>
<td>Traffic sign used across the motorway and A-road network to inform drivers, and to accurately describe their location where an incident occurs</td>
</tr>
<tr>
<td>DR</td>
<td>Detection Rate</td>
</tr>
<tr>
<td>DSRC</td>
<td>Dedicated Short Range Communication - Short range wireless communication channels in the ~5.9GHz frequency range</td>
</tr>
<tr>
<td>Dynamic Speed Adaption</td>
<td>A system that aids the drivers maintaining road speeds compliant with relevant local statutory or desirable speed limits</td>
</tr>
<tr>
<td>Dynamic speed limits</td>
<td>Speed limits that take account of the real time traffic, road and weather conditions</td>
</tr>
<tr>
<td>Dynamic time warping</td>
<td>Algorithm for measuring the similarity between two temporal sequences, which may vary in time or speed</td>
</tr>
<tr>
<td>ERA</td>
<td>Emergency Refuge Area - Safe area, provided at regular intervals on Smart Motorways in lieu of a hard shoulder, for vehicles to use in the event of an emergency</td>
</tr>
<tr>
<td>ETC</td>
<td>Electronic Toll Collection</td>
</tr>
<tr>
<td>ETSI</td>
<td>European Telecommunications Standards Institute</td>
</tr>
<tr>
<td>Expressway</td>
<td>A highway especially designed for high speed traffic, largely dual carriageway, with grade separated and left turn only junctions</td>
</tr>
<tr>
<td>FAR</td>
<td>False Alarm Rate</td>
</tr>
<tr>
<td>Floating car data</td>
<td>Method to determine traffic speed on the road network based on the collection of localization data, speed and direction of travel and</td>
</tr>
</tbody>
</table>
time information from mobile phones in vehicles that are being
driven on the network

Flow breakdown
Traffic state where the sheer weight of traffic causes traffic to slow
and/or stop

Fuzzy logic
Approach to computing based on ‘degrees of truth’ rather than
Boolean Logic ‘true or false’ (1 or 0)

FVD
Floating Vehicle Data – see floating car data

GPRS
General Packet Radio Services (GPRS) is a packet-based wireless
communication service that promises data rates from 56 up to 114
kilobits per second (kbps) and continuous connection to the Internet
for mobile phone and computer users

GPS
Global Positioning System

Hardware Security Module
A physical computing device that safeguards and manages digital
keys for strong authentication and provides crypto-processing

Heuristic
Using experience to learn and improve

HIOCC
High OCCupancy

Hybrid neuro - fuzzy system
Algorithm using the concept of fuzzy logic into the neural networks,
resulting in a hybrid intelligent system that combines the human-like
reasoning style of fuzzy systems with the learning and connectionist
structure of neural networks

IEEE
The Institute of Electrical and Electronics Engineers

Instation
RCC-based equipment that can process data from many sites

Interoperability
The ability of systems, especially computers or telecommunications
that are capable of working together without being specially
configured to do so

IP
internet protocol

ISA
Intelligent Speed Adaption; uses two way communication between a
traffic management system and an in-vehicle unit that supports
drivers’ compliance with the speed limit or speed advice

ISO
International Organisation for Standardisation

ITS
Intelligent Transportation Systems

IVD
Individual Vehicle Data

LTE
Long Term Evolution - A standard for wireless communication of
high-speed data for mobile phones and data terminals, also
commonly referred to as 4G

Machine learning
Type of artificial intelligence that provides computers with the
ability to learn without being explicitly programmed

Managed Motorway
Previous name of a SMART motorway

MCS
Motorway Control Systems
Metaheuristic
A high-level problem-independent algorithmic framework that provides a set of guidelines or strategies to develop heuristic optimization algorithms

MIB
Management Information Database - A database used for managing the entities in a communication network

MIDAS
Motorway Incident Detection and Automatic Signalling

MS1
Motorway Signal Mark 1 - Post mounted matrix signal normally located in the central reserve

MS4
Motorway Signal Mark 4 - Cantilever or gantry mounted signal capable of displaying a wide range of red and “off white/yellow” bitmap images

MTCC
Motorway Traffic Control Centre

Network protocol
Rules and conventions for communication between network devices

Neural network
Artificial Intelligence technique that mimics the operation of the human brain

NMUs
Non-Motorised Users: pedestrians, cyclists and equestrians

NOx
Nitrogen Oxide(s) - Blanket term covering oxides of nitrogen, which are associated with health risks (commonly NO and NO2)

NRTS
National Roads Telecommunications Services

OEM
Original Equipment Manufacturer

OSI model
Open Systems Interconnection model - A conceptual model that characterizes and standardizes the internal functions of a communication system by partitioning it into abstraction layers

Outstation
Roadside equipment that processes data from a single site

Partial Least Squares
Statistical method for constructing predictive models where there are many factors that are highly collinear, i.e. that lie on the same straight line

PeMS
Performance Measurement System

PLC
Programmable Logic Controller – A special computing device used for industrial control systems

PM10
Particulate matter of 10 micrometres or less

Probabilistic neural network
A Neural network derived from the Bayesian network and a statistical algorithm called Kernel Fisher discriminant analysis

Probabilistic Topic Model
Suite of algorithms whose aim is to discover the hidden thematic structure in large archives of documents

QP
Queue Protection - A reactive speed-based system to protect slow moving traffic

Ramp Metering
A system to control the flow of traffic onto motorways at times of high flow
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression analysis</td>
<td>A statistical tool for the investigation of relationships between variables</td>
</tr>
<tr>
<td>RCB</td>
<td>Rigid Concrete Barrier - Safety barrier, constructed from concrete, installed permanently in the central reservation of a motorway</td>
</tr>
<tr>
<td>RCC</td>
<td>Regional Control Centre</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>Seedpoint</td>
<td>A location at which flow breakdown occurs</td>
</tr>
<tr>
<td>SM</td>
<td>Smart Motorway - An actively controlled motorway, some of which have no hard shoulder that are using technology to manage congestion</td>
</tr>
<tr>
<td>SMART motorway</td>
<td>An actively controlled motorway, some of which have no hard shoulder, that are using technology to manage congestion</td>
</tr>
<tr>
<td>SUMO</td>
<td>Simulation of Urban Mobility - Open source microscopic traffic simulation package</td>
</tr>
<tr>
<td>Support Vector Machine</td>
<td>A supervised machine learning algorithm used for classification or regression analysis</td>
</tr>
<tr>
<td>Tabu Search</td>
<td>Technique based on selected components from artificial intelligence; a general heuristic procedure for guiding search to obtain good solutions for mathematical optimization</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission Control Protocol - A standard that defines how to establish and maintain a network conversation via which application programs can exchange data</td>
</tr>
<tr>
<td>Time Series Analysis</td>
<td>An ordered sequence of values of a variable at equally spaced time intervals</td>
</tr>
<tr>
<td>Thresholds</td>
<td>Flow levels at which signals to manage traffic are switched on and off; speed thresholds are also available within the CM algorithm</td>
</tr>
<tr>
<td>TPEG</td>
<td>Transport Protocol Experts Group - A data protocol suite for traffic and travel related information</td>
</tr>
<tr>
<td>UTMS</td>
<td>Universal Mobile Telecommunications Service - A third-generation (3G) broadband, packet-based transmission of text, digitized voice, video, and multimedia at data rates up to 2 megabits per second (Mbps)</td>
</tr>
<tr>
<td>UDP</td>
<td>User Datagram Protocol - An alternative communications protocol to TCP used primarily for establishing low-latency and loss tolerating connections between applications on the Internet</td>
</tr>
<tr>
<td>V2I</td>
<td>Vehicle to Infrastructure - Term meaning two way communication between road vehicles and road side units (or other infrastructure)</td>
</tr>
</tbody>
</table>
V2V  Vehicle to Vehicle – Term meaning two way communication between road vehicles

V2X  Vehicle to ‘X’ – Umbrella term used to refer to vehicle to vehicle and/or vehicle to infrastructure communications

VISSM  Microscopic multi-modal traffic flow simulation software

VMS  Variable Message Sign

VMSL  Variable Mandatory Speed Limits

3-VMSL  3-lane variable mandatory speed limits

4-VMSL  4-lane variable mandatory speed limits

VSL  Variable Speed Limits

Watchdog  A function within HIOCC2 that filters occupancy alerts from HIOCC

WAVE  Wireless Access in Vehicular Environments - Amendment to the US IEEE 802.11 wireless (Wi-Fi) standard to support for two-way communication in an ITS environment

Wavelet  A mathematical function, the principles of which are similar to those of Fourier analysis

WLAN  Wireless Local Area Network

WLD  Wireless Local Danger Warning

2G  Second-generation wireless telephone technology, commercially launched on the GSM standard in 1991

3G  Third- generation wireless - A generic term for network technologies that the International Telecommunication Union (ITU) classifies as part of their IMT-2000 specification

4G  Fourth-generation wireless - A mobile communications standard intended to replace 3G, allowing wireless Internet access at a much higher speed

5G  Fifth-generation wireless - A networking architecture built on the 802.11ac IEEE wireless networking standard, which aims to increase data communication speeds by up to three times compared to its predecessor
8 References/Bibliography


29. ETSI. (2010). Intelligent Transport Systems (ITS); Communication Architecture. ETSI.


Appendix A

A.1 Summary of research findings for existing automatic incident detection algorithms

A.1.1 Enhancement/modification of existing automatic incident detection algorithms

Enhancement of Automatic Incident Detection Algorithms for Singapore's Central Expressway

Summary
The purpose of this study is to investigate the factors that influence incident detection performance. Research findings were used to enhance the existing calibrated incident detection algorithms for an expressway in Singapore. Results of the study indicated that the inclusion of pre-incident traffic flow, or occupancy conditions and the use of traffic speed, together with occupancy, in an algorithm would yield enhanced detection performance. Of the algorithms studied, the dual variable algorithm, which uses traffic speed and occupancy, consistently gave the best incident detection performance. A comparative evaluation of different types of algorithm suggested that the occupancy-based algorithms were generally more effective than the flow-based algorithms in detecting incidents.

Reference

An Investigation into the Evaluation and Optimization of the Automatic Incident Detection Algorithm Used in TxDOT Traffic Management Systems

Summary
This study proposes a minimal modification to the incident detection comparative algorithm which decreases false alarms and increases the detection rate, as determined by a multi-year assessment of its performance characteristics, using archived data. The project delivered a revised comparative algorithm, a procedure for setting incident detection thresholds, a logic flow for an automated tool, and recommendations for improving the incident detection process and data archives.

Reference
A.1.2 Comparative evaluations of incident detection algorithms currently in use

Overview to Some Incident Detection Algorithms: A Comparative Evaluation With Istanbul Freeway Data

Summary
Selected incident algorithms are tested within simulation, calibrated with flow measures obtained from a section of the Istanbul freeway network. The performances of these algorithms are compared in terms of statistical performance measures: false alarm rate, detection rate and mean-time to detect.

Reference

Investigation of Five Dutch Incident Detection Algorithms

Summary
An investigation into how the current loop detector data of traffic speed and flow can be used to detect incidents. A comparison is made of an earlier Dutch algorithm with several different algorithms. Results of this comparison showed that one specific algorithm offered improvements over the original algorithm and another algorithm offered potential improvements.

Reference
http://www.modelit.nl/modelit/pdf/IncDet_IFAC06.pdf


Summary
An assessment of the strengths and limitations of available sensor technologies and their corresponding algorithms, reviewing and evaluating three categories of incident detection technologies and their corresponding algorithms.

Reference
http://www.uvm.edu/~transctr/pdf/netc/netcr37_00-7.pdf

Comparison and Analysis Tool for Automatic Incident Detection

Summary
A test bed, called the AID comparison and analysis tool, was developed for automatic incident detection systems using real-time traffic video data and data feeds from the Ontario Ministry of Transport COMPASS advanced traffic management system. This test bed is used to calibrate and then analyse the performance of three AID algorithms: California Algorithm 8, the McMaster
Algorithm Improvement

algorithm, and the genetic adaptive incident detection algorithm. In the calibration and testing process, nuisance rate and false normal rate are introduced as two new performance measures to supplement the three traditional measures (detection rate, false alarm rate, and mean time to detection).

Reference

Assessment of the Current Status of Incident Detection Algorithms: Results of a Nationwide Survey
Summary
This paper investigates the causes of limited implementation of the use of automatic incident detection algorithms. This investigation entailed a survey of stakeholders. Results of this survey pointed to general consensus of unacceptably high false alarm rates by incident detector algorithms. This study also allowed a direct comparison to be made of technologies between conventional incident detection and automatic incident detection.

Reference
http://people.umass.edu/ndh/Publications/C07.pdf

Incident Detection Algorithm Evaluation
Summary
This research examines a range of incident detection technologies to determine recommended combinations of approaches for use in the Utah Department of Transport’s Advanced Traffic Management System. Results indicated that the All-purpose Incident Detection algorithm performed well, giving eight false alarms per peak hour with an 86% detection rate and 2.5 minutes to detect. The neural network method performed well, with two false alarms per peak hour with an 89% detection rate and 1 minute to detect. Incident detection by video image also performed well with 0.03 false alarms per hour, a 90% detection rate and 20 seconds to detect.

Reference

Evaluation of Automatic Vehicle Identification for San Antonio’s Transguide for Incident Detection and Advanced Traveler Information Systems
Summary
This report describes a systematic evaluation of the performance of Automatic Vehicle Identification (AVI) as a basis for incident detection, and for traffic state estimation information for public dissemination. Extensive testing and calibration of AVI algorithms is undertaken and performance is compared.

Reference

Development and Testing of Operational Incident Detection Algorithms: Executive Summary

Summary
This Executive Summary provides an overview of the different volumes of this report.

Reference

Comparative Performance of Freeway Automated Incident Detection Algorithms

Summary
An evaluation of the performance of the incident detection algorithm currently implemented on Melbourne’s freeways based on a set of 100 incidents that occurred under varying traffic conditions. Algorithm performance was evaluated in terms of detection rate, false alarm rate and mean-time to detect. Results demonstrated the substantial improvement in incident detection performance using the Artificial Neural Networks (ANN) model over the ARRB/VicRoads model.

Reference
Appendix B

B.1 Algorithms of congestion management, including ramp metering

A Multi-Hierarchical Motorway Ramp Signalling Strategy (2013)

Summary
This study proposes a multi-hierarchical strategy for co-ordinated ramp signalling. This strategy is modelled and then applied to the northbound Pacific Motorway micro-simulation platform (AIMSUN). Results of the simulation showed that the proposed strategy provided an effective mitigation of congestion.

Reference

Queue Protection Parameters Fine Tuning for Variable Speed Limits - Queensland University of Technology, Australia

Summary
This paper describes the fine tuning of the Queue Protection algorithm for Variable Speed Limits (VSL). It presents the performance and benefits of VSL during an incident and during heavy traffic congestion.

Reference

Coordinated Ramp Metering Control with Variable Speed Limits for Swiss Freeways

Summary
This research project explores alternative methods for developing the next generation of ramp metering strategy to address the limitations of widely used existing strategies and enhancing the performance of the current traffic situation in the Swiss freeway system. A new coordinated ramp metering strategy is developed with variable speed limits, focusing on densities and flows obtained by loop detector measurements. The second part of the project developed a dynamic zone-based coordinated ramp metering algorithm with variable speed limits considerations to treat all freeway and urban road users equally.

Reference
Algorithm for Queue Estimation with Loop Detector of Time Occupancy in Off-Ramps on Signalized Motorways

Summary
The problem of queue estimation is identified, with the interpretation of queuing dynamics and the corresponding time-occupancy distribution over motorway off-ramps. A novel algorithm for real-time queue estimation is discussed. The effectiveness of the algorithm was validated from microscopic traffic simulation, which also revealed some useful features of the algorithm: accurately measuring intermediate and long traffic queues, a relatively simple detector input and the estimation philosophy was independent with signal timing changes.

Reference

Adaptive Fuzzy Algorithms for Traffic Responsive and Coordinated Ramp Metering

Summary
This paper describes new adaptive fuzzy algorithms for coordinated ramp metering. The new model was developed to overcome the limitations of existing coordinated ramp metering algorithms. The genetic fuzzy models are explained, evaluated via simulation, and compared with other ramp metering approaches in a simulation scenario for a German Autobahn. Preliminary evaluation results of this real world implementation look very promising.

Reference
http://asclibrary.org/doi/abs/10.1061/40632(245)94

Integrated Network Management

Summary
A co-ordinated approach to congestion management on freeways and arterial roads is currently being trialled in Amsterdam and the concept developed for Melbourne. The aim is to combine data from infrastructure, sensors, mobile devices and communication systems to build a “predictive control framework to minimise congestion”. This is a mathematical model inspired by packet scheduling models for wireless networks. Phase 1 in Amsterdam went live in 2013 to control ramp metering sites. A further phase is looking at in-car information. The algorithm has the potential to output signal phasings, VMS, in-car data and variable speed limits.

References
http://www.swinburne.edu.au/news/latest-news/2016/05/models-reduce-traffic-mayhem-.php (accessed on 19/05/2016)

Hoogendoorn, Van Kooten and Adams: Lessons learnt from the Field Operational Test Integrated Network Management in Amsterdam (TRB ‘Practice Ready Paper’: docs.trb.org/prp/16-2888.pdf)
Appendix C

C.1 Summary of research findings for new incident detection algorithms

Real Time Freeway Incident Detection

Summary
This paper describes an evaluation of two recently developed automatic incident algorithms (Dynamic Time Warping (DTW) and Support Vector Machine (SVM)) in recognising traffic pattern changes when incidents occur during stop and go conditions. This study describes a case study evaluation of these automatic incident detection methods using data from the Dallas, TX traffic centre.

Reference
http://d2dtl5nnlpr0r.cloudfront.net/swutc.tamu.edu/publications/technicalreports/600451-00083-1.pdf

Real-Time Traffic incident Detection Using a Probabilistic Topic Model

Summary
This article proposes a new method of detecting traffic incidents from probe-car data by identifying unusual events that distinguish incidents from spontaneous congestion. A traffic state model was developed based on a probabilistic topic model to describe the traffic states for a variety of roads. To evaluate discrimination and detection performance, the model was applied to real traffic data. Results indicated that the model successfully discriminated between anomalous car trajectories and the more usual, slowly moving traffic patterns.

Reference

Automatic Incident Detection for Urban Expressways Based on Segment Traffic Flow Density

Summary
This article proposes an incident detector algorithm for urban expressways using loop detector data. The expressway is divided into short segments, and the loop data is used to calculate the defined equivalent upstream and downstream traffic flow density differences. The performance of this algorithm was tested on an expressway in China and compared with classic automatic detector algorithms, performed well and is considered suitable by the authors for urban expressways.

Reference
A Weather-Responsive Automatic Incident Detection Algorithm with Generalized Detection Thresholds

Summary
This paper proposes a weather-responsive automatic incident detection algorithm with generalized detection thresholds for incident detection under no rain and rain conditions. In the proposed algorithm, a detection threshold function is adopted to generalize the relationship between the threshold and the pre-incident traffic flow. Traffic data, accident data and rainfall data were collected on a selected road network to calibrate and validate the proposed algorithm.

Reference
http://trid.trb.org/view/2014/C/1287625

Support Vector Machine with the Tabu Search Algorithm for Freeway Incident Detection

Summary
This article describes a method of improving the accuracy of detecting incidents on expressways. The tabu search algorithm was employed to optimize the Support Vector Machine (SVM) parameters which can improve prediction accuracy. The model was evaluated with real traffic data in China. Results showed that the tabu search algorithm can effectively provide better parameter values for the SVM and SVM models outperformed Artificial Neural Networks (ANNs) in freeway incident detection.

Reference

A Hybrid Approach for Automatic Incident Detection

Summary
This paper presents a hybrid approach to automatic incident detection that combines time series analysis (TSA) and machine learning (ML) techniques. The time series component forecasts normal traffic for the current time point based on prior traffic and the ML component detect incidents using real time traffic and predicted normal traffic. Validation was undertaken using a real-world data set. Results showed that the hybrid approach is able to detect incidents more accurately and faster (a shorter mean time to detect) under the requirement of a similar false alarm rate, compared with state-of-the-art algorithms.

Reference
A Hybrid Model of Partial Least Squares and Neural Network for Traffic Incident Detection

Summary
This article describes a hybrid incident detection algorithm, which combines the partial least squares (PLS) method and an artificial neural network (NN), to automatically detect a traffic incident. Real traffic data was presented to illustrate the approach. Detection performance was evaluated by the common criteria including detection rate, false alarm rate, mean-time to detection, classification rate and the area under the curve of the receiver operating characteristic. Results showed that the hybrid approach is capable of increasing detection performance comparing to PLS, and simplifying the NN structure for incident detection and the hybrid model is a promising alternative to the usual PLS or NN for incident detection.

Reference

Algorithm Fusion Method to Enhance Automatic Incident Detection on Melbourne freeways

Summary
This paper describes a study to develop an algorithm fusion method that was evaluated on freeways in Melbourne to demonstrate its transferability potential in detecting lane-blocking incidents. This study established the flow-based algorithm fusion options that use a set of different detection threshold values for various pre-incident traffic flow conditions possess transferability potential. These algorithms gave a reasonably high detection rate of above 80% with false alarm rate levels below 0.2% with mean-time-to-detect values less than 150 seconds.

Reference
http://www.tandfonline.com/doi/abs/10.1080/03081060.2013.870790

D-S Theory Data Fusion Based Automatic Incident Detection Algorithm for Expressway

Summary
This paper describes the development of algorithms based on fixed detector data and floating car data. The two algorithms were integrated effectively according to the Dempster - Shafer (D-S) theory. The algorithms were validated with fixed detector data, floating car data and event data collected from the Beijing expressway. Results showed the algorithms based on single data could meet basic practical application needs at detection rate and false alarm rate; the integrated detection algorithm based on D-S theory had better performance than the classical algorithms at false alarm rate.

Reference
http://trid.trb.org/view/2011/C/1255626
A Combination Algorithm of Freeway Traffic Automatic Incident Detection

Summary
This paper introduces an algorithm which combines the California algorithm and the filter algorithm. From simulation studies it was shown that, compared with the single application of either California algorithm or the filter algorithm, the combination algorithm can enhance detection rates and effectively reduce false alarm rates without increasing software or hardware costs.

Reference

A Wavelet-Based Freeway Incident Detection Algorithm with Adapting Threshold Parameters

Summary
This paper presents a wavelet-based freeway novel automated incident detection algorithm with varying threshold parameters considering the level of traffic flow. For a given target false alarm rate, the threshold values can be changed adaptively depending on the traffic levels of normal traffic conditions. Using both simulated and real-life incident data sets, the performance of the algorithm was compared with existing algorithms, such as California algorithm, Minnesota algorithm and conventional neural networks algorithms. Results showed that the wavelet-based algorithm consistently outperformed the other algorithms with a higher detection rate, lower false alarm rate, and shorter mean-time to detection.

Reference

Urban Expressway Incident Detection Algorithm Based on Floating Car Data

Summary
This article describes an automatic incident detection algorithm based on two-dimensional integration, analysing floating car data and traffic event data. The algorithm integrates the change of speed by the standard difference in the temporal dimension and the difference between travel speed on upstream and downstream in the spatial dimension to detect incidents. The algorithm was verified with the floating car data and traffic incident data collected from an expressway, with an 87% detection rate and a 1.86% false alarm rate.

Reference
Incident Detection Algorithm Based on Partial Least Squares Regression

Summary
This article presents the development of freeway incident detection models based on the partial least squares regression (PLSR). Detection performance was evaluated using the common criteria of detection rate, false alarm rate, mean-time to detection. Experiments investigated the potential application of PLSR to automatic incident detection using simulated traffic data from an expressway in Singapore and real traffic data from a freeway in California. Experimental results demonstrated that the PLSR model is comparative to a Multi-Layer Feed (MLF) neural networks and Support Vector Machine (SVM) implementation for Automatic Incident Detection applications. PLSR has the potential for the application of automatic incident detection in the real world.

Reference

Traffic Incident Detection Algorithm for Urban Expressways Based on Probe Vehicle Data

Summary
This paper proposes an automated incident detection algorithm for urban expressways based on probe vehicle data by the CUSUM algorithm based approach. Its performance was evaluated and compared with that of an existing probe-vehicle-based incident detection UCB algorithm. Results showed that the performance of the proposed algorithm under 1-minute time interval was better than that under 5-minute time interval. It was observed that the performance of the proposed algorithm was better than that of the UCB algorithm. Under the same false alarm rate, the detection rate of the proposed algorithm was improved by 10%.

Reference

Freeway Incident Detection using Hybrid Fuzzy Neural Network

Summary
A new technique is described in this article for freeway incident detection using a hybrid neuro-fuzzy system. Real freeway traffic data tested the effectiveness of the developed fuzzy-neural system. To assess the transferability of the system, the network was trained on AYE dataset from Singapore and then adapted onto I-880 dataset from USA. The system was shown to be highly adaptable giving excellent results after adaptation. Results obtained showed high potential for the application of this system to freeway traffic incident detection.

Reference
Development of Proactive Incident Detection Algorithm by Adopting Hybrid Model

Summary

This paper attempts to provide an artificial intelligence-based solution using artificial neural network and neuro-fuzzy algorithm. The proposed incident detection model consisted of artificial neural network which estimates suspected time and location of incident, then the neuro-fuzzy algorithm that determines exact incident time and location based on the previous result of the neural network model. The hybrid model revealed a high detection rate of 83% and a low false alarm rate of 0.017%.

Reference


Towards Universal Freeway Incident Detection Algorithms

Summary

This paper describes the findings of intensive tests of the new transport systems centre algorithm applied to incident detection on freeways. The algorithm consists of two modules: a data processing module and incident detection module. The algorithm was tested using field incident data sets obtained from freeways in Melbourne, Australia. It was found that the detection rate and false alarm rates were not sensitive to the incident decision threshold, which greatly improved the stability of incident detection.

Reference


Algorithm Fusion for Detecting Incidents on Singapore’s Central Expressway

Summary

This article describes the development of an algorithm fusion method using incident data collected from an expressway in Singapore. This method explored the possibility of enhancing incident detection performance by combining the complementary advantages of a group of existing algorithms. It was found that the fused algorithm outperformed existing algorithms. Compared with existing algorithms for the same study site, the fused algorithms performed significantly better, with false alarm rates between 0.2 and 1.0%. At a detection rate of 90%, these fused algorithms were able to reduce the false alarm rate by more than 55%.

Reference


http://trid.trb.org/view/778872
Heavy Flow-Based Incident Detection Algorithm using Information from Two Adjacent Detector Stations

Summary
This article describes two new video-based automatic incident detection algorithms: the Individual Detection Evaluation algorithm and the Combined Detection Evaluation algorithm. These algorithms were developed for the detection of lane-blocking incidents in heavy traffic flow conditions, using a Singapore expressway as a case study. Both algorithms outperformed existing algorithms commonly used in incident management systems. The Individual Detection Evaluation algorithm raised fewer false alarms and gave slightly faster incident warnings however its performance was relatively less consistent when applied to a validation database.

Reference

Effective Arterial Road Incident Detection: A Bayesian Network Based Algorithm

Summary
A new arterial road incident detection algorithm is presented in this paper. Bayesian networks are used in this algorithm to quantitatively model the causal dependencies between traffic events (e.g. incidents) and traffic parameters. A total of 40 different types of arterial road incidents were simulated to test the performance of the algorithm. The high detection rate of 88% is obtained, whilst the false alarm rate is as low as 0.62%. It was found that both the detection rate and false alarm rate are not sensitive to the incident decision thresholds.

Reference

A New Incident Detection Scheme Developed in the Netherlands

Summary
This paper describes a new scheme that employs real-time traffic speed and flow data for incident detection. From field tests performed over several months, it appears that this algorithm can provide useful low cost detection where real-time traffic data is available.

Reference
Adaptive Neural Network Models for Automatic Incident Detection on Freeways

Summary
Three neural network models were evaluated for their incident detection performance: multi-layer feed-forward neural network (MLF), basic probabilistic neural network (BPNN) and constructive probabilistic neural network (CPNN). The models were developed and tested on a freeway in Singapore, and tested for their adaptability on a freeway in the US. Results indicated that the CPNN model outperforms the other two models in terms of its adaptability and flexible structure. Results suggest that the CPNN model has the greatest potential for use in an operational incident detector system for freeways.

Reference

Detection-Delay-Based Freeway Incident Detection Algorithms

Summary
In this study, incident detection was formulated as an optimization problem. To implement the algorithm, called the CUSUM algorithm, a procedure was developed where three variations of the CUSUM algorithm were developed and tested based on real incident data against a newly defined criterion for mean detection delay. Selected incident detection algorithms were also compared with the CUSUM algorithms. Results indicated that the CUSUM algorithms performed better than other selected algorithms in terms of both corrected mean detection delay and detection rate versus false alarm rate.

Reference

Mobile Sensor and Sample – Based Algorithm for Freeway Incident Detection

Summary
This paper describes a mobile sensor and sample-based statistical algorithm (MOSES) that detects incidents on freeways. The incident detection performance was tested on a data set generated by a calibrated microscopic traffic simulation model. Results were compared with those of two of the most promising neural network incident detection models. When more than 50% of the vehicles are sampled as probes, MOSES can achieve a detection rate and false alarm rate comparable to that of the two neural network models, but with faster mean time to detection and lower misclassification.

Reference
Enhancing Neural Network Traffic Incident-Detection Algorithms Using Wavelets

**Summary**
This article describes how the performance of a fuzzy neural network algorithm for freeway traffic incident detection can be improved through pre-processing of data using a wavelet-based feature-extraction model, as use of the wavelet theory to ‘de-noise’ the traffic data increases the incident-detection rate, reduces the false-alarm rate and the incident-detection time.

**Reference**

Wavelet - Neural Network Model for Automatic Traffic Incident Detection

**Summary**
This paper describes a method of overcoming the computational complexity of neural network algorithms increasing exponentially with the size of the network, resulting in an increase in the size of the training set to achieve the same level of accuracy, a hybrid feature extraction algorithm and neural network architecture was created for automatic detection of traffic incidents.

**Reference**

An Integrated Traffic Incident Detection Model

**Summary**
This study develops algorithm fusion methods for improving the reliability of Automatic Incident Detection (AID) systems, reducing incident detection mean time and false alarm rates. Real world traffic data was used to evaluate the incident detection performance of AID algorithms. A model was developed to integrate all available incident detection sources and reduce typical false alarm rates, whilst increasing detection rate to an expected level. The study also tested and validated the model using operational traffic and incident databases.

**Reference**
http://trid.trb.org/view/2000/M/731253

Towards Adaptive Incident Detection Algorithms

**Summary**
This research builds on previous successful work with neural networks and automates the training of detector algorithms to allow for on–site retraining after transferability. Two approaches are used in developing an adaptive incident detection algorithm, i.e. single parameter Probabilistic Neural Network (PNN) and a multi-parameter version of PNN, focusing on the second approach, a Genetic Adaptive PNN (GAPNN).

**Reference**

**Traffic Incident Management Handbook**

*Summary*

The Traffic Incident Management (TIM) handbook includes the latest advances in TIM programmes and practices across the US and offers insights into the latest innovations in TIM tools and technologies.

*Reference*

Appendix D

D.1 C-ITS Architecture & Enabling Technologies

At the core of C-ITS is unidirectional low latency communication of data, and to achieve this exchange across different systems and modules there is a large emphasis on compatibility and reliability at all system layers. This section will include an outline of ITS architecture as defined by the International Organisation for Standardisation (ISO) and European Telecoms Standard Institute (ETSI) bodies and the prominent technologies in each layer of a C-ITS system. To illustrate this architecture and its possible elements, Figure 3 sourced from the ETSI paper on ITS communication architecture (ETSI, 2010) is included.

While the Applications, Security and Management layers are higher elements that are addressed in other sections the three layers of Facilities, Network & Transport and Access are the communication core of the ITS architecture; this section will discuss prominent technologies used in emerging or prototype C-ITS systems which operate in each of these sections. For reference these three core levels encapsulate the Open Systems Interconnection (OSI) model concept; the Facilities layers represents OSI layers 5, 6 and 7, Network & Transport representing layers 3 and 4 while Access represents OSI layers 1 and 2 (ETSI, 2010).

![Figure 3 - ITS Architecture with potential layer elements (ETSI, 2010)](image-url)
**D.1.1 Access layer**

The most fundamental level of communication within the C-ITS architecture this layer covers the physical media and their standards for data exchange. The three technologies covered here are the most common but by no means the only ones used in C-ITS applications.

**D.1.1.1 5 GHz spectrum**

Wireless communications in this spectrum are emerging as a dominant method of cooperative communications, and have undergone several different evolutions and standardisations:

**D.1.1.2 Dedicated Short Range Communication (DSRC)**

One or two-way short range wireless communication channels designed specifically for use in automotive applications. Initially allocated in the 5.850-5.925 GHz band by the US Federal Communications Commission the system enjoyed some use in toll collection; however DSRC systems tended to be incompatible from locality to locality and are generally considered legacy systems. Some other standards such as Communication Access for Land Mobile (CALM) take into account compatibility with DSRC systems. It is worth noting that though the initial DSRC band refers to a specific allocation the phrase DSRC is used as an umbrella term for short range wireless with ~5.9GHz frequency including subsequent evolutions.

**D.1.1.3 IEEE 802.11p WAVE**

An approved amendment to the US IEEE 802.11 wireless (Wi-Fi) standard to add ‘Wireless Access in Vehicular Environments’ (WAVE) i.e. support for two-way communication in an ITS environment where timings on data exchanges are brief. 802.11p (or standards based on it) is used widely as a basis for standardising vehicles communications in C-ITS platforms (even in a European setting).

**D.1.1.4 CALM M5**

CALM M5 is an ISO standard which incorporates a European 5GHz spectrum, some regional cooperation with DSRC systems and interconnectivity with cellular networks (GPRS, UTMS etc.). CALM M5 was thoroughly tested as a wireless standard in the CVIS project whose aim was to develop a reliable wireless standard for C-ITS platforms.

**D.1.1.5 ETSI ITS-G5**

European Telecommunications Standards Institute (ETSI) used 802.11p as a basis for the ITS-G5 European standard for vehicle to infrastructure and vehicle to vehicle communication. ITS-G5 is widely used in C-ITS projects in Europe for instance in the Compass4D project.

**D.1.1.6 Mobile cellular**

While 5 GHz wireless and infrared communications are used for short to medium distance, cooperative systems often make use of mobile cellular networks to transmit data both between vehicles and infrastructure over a medium distance but also for longer communications as well. To this end 2G GPRS/UTMS and 3G UTMS cellular communications are used in addition to the more modern Long Term Evolution (LTE; aka 4G). A good example of the utilisation of LTE in C-ITS projects is in the compass4D project trial site in Verona; this use is being expanded on as part of the next generation of connected corridors projects such as NordicWay.
D.1.2 Network & transport layers

This layer contains the networking and transport protocols, some types of which are generic and other are ITS specific. Transport protocols include UDP/TCP and some others (ETSI, 2010) while the following examples are all network protocols:

D.1.2.1 IPv6

This is the latest version of the Internet Protocol designed in part to tackle the issue of IPv4 address exhaustion. This newer protocol is often used in C-ITS projects because of the high volume of addresses required for an ad-hoc vehicular network, often multiple IP addressed per vehicle and the in-built mobility of IPv6 which is vital for cooperative applications where network nodes are often mobile.

D.1.2.2 CALM Fast

One of the many CALM standards (ISO 29281); Fast is a network protocol for ‘single hop unicast/n-hop broadcast communications’. For the CVIS and SAFESPOT project the CALM Fast protocol is used because of its simplicity.

D.1.2.3 GeoNetworking

Another protocol which provides packet routing in an ad-hoc network; the key feature of the GeoNetworking protocol is that it makes use of geographical positions for packet transport between individual C-ITS nodes or disseminated across an entire network. The protocol can be used with any short range wireless access layer technologies such as ESTI G5 and infrared.

D.1.3 Facilities layer

This layer of protocols and message sets determines the data content delivered at the access layer, notable examples used in many of the projects examined in this report include:

D.1.3.1 TPEG

Transport Protocol Experts Group (TPEG) developed the TPEG protocol as a method for unidirectional transmission of traffic data. TPEG is independent of transmissions medium and language and can be used with any of the technologies employed in C-ITS. Used by (for instance) the COOPERS and eCoMove projects the messages consist of three parts: management container, applications container and location container. TPEG is gaining popularity as a method of transporting traffic and travel information, as well as potential C-ITS applications.

D.1.3.2 ETSI TC ITS messages

At the facilities layers the ETSI TC ITS standard has two types of defined message; Cooperative Awareness Message (CAM) and the Decentralised Environmental Notification Messages (DENM). While DENM supports road hazard warning applications CAM exchanges data with other elements periodically to facilitate cooperative awareness. Both messages use ETSI G5 (802.11p) wireless media. CAM is single hop and provides information on presence, position and general status of the C-ITS elements to their neighbours within range.
D.1.3.3 SAE J2735

This US based Society of automotive engineers standard specifies message sets as well as data element and frames for use with 5.9GHz wireless communication units. The standard includes a variety of applications for the messages.
Appendix E

E.1 Air quality

4-Lane Variable Mandatory Speed Limits

Summary
This report highlights the findings from the six months results from the M42-ATM section which show that VMSL offers “a significant improvement in traffic conditions on the M42-ATM section compared with NO-VSL and 3L-VMSL. 4L-VMSL has delivered consistent, measurable benefits that are supported by user consultation.”

The environmental benefits from 4L-VMSL include reduced noise impacts; fuel consumption reduced by 4%; emissions have been reduced by 4-10% except for hydrocarbons, which increased by 3%.

Reference

Reducing speed limits on highways: Dutch experiences and impact on air pollution, noise-level, traffic safety and traffic flow

Summary
Analysis of the effect of the reduction in speed limits on motorways near urban areas in the Netherlands, and what effect these zones have on air quality and other factors affecting the road network. These are quantified with figures and were shown to have reduced air pollution.

Reference

Air quality effects of an urban highway speed limit reduction

Summary
This study set out to analyse whether the “lowering of the maximum speed limit from 100 to 80 kph had reduced traffic related air pollution in the direct vicinity of a highway”. The study found an overall reduction in pollutants, especially particulate matter, but did not find that the sections with the speed limit intervention had more congestion that those which were left unchanged.

Reference
Reduced speed limits for local air quality and traffic efficiency

Summary
Summarises the effects of the implementation of reduced speed limits of 80kph (with strict enforcement) on sections of the Dutch motorway network which are near cities to improve air quality. The report concludes that emission “reductions of NOx are about 20-30% while PM10 traffic emission reductions have been measured of about 10%”.

Reference

Air pollution impacts of speed limitation measures in large cities: The need for improving traffic data in a metropolitan area

Summary
Although this study is focused on an urban setting, it still offers relevant information due to the analysis on the introduction of maximum speed limits of 80kph on motorways in large cities by “using a novel methodology combining traffic assimilation data and modelling systems implemented in a supercomputer facility.” The case study used in this instance is Barcelona; however it is argued that this concept can be extrapolated to any large city. The system has reduced emissions by up to 4%: “however the local effects of this reduction achieve an important impact for the adjacent area of the roadways, reaching 11%.”

Reference
https://www.bsc.es/media/3487.pdf

Effects of the 80 km·h⁻¹ and variable speed limits on air pollution in the metropolitan area of Barcelona

Summary
Compares the effects of the maximum speed limit of 80 kph on motorways around Barcelona with the variable speed system introduced on other stretches of its metropolitan motorways. The study found that “Empirical estimation indicate that reducing the speed limit to 80 kph causes a 1.7 to 3.2% increase in NOx and 5.3 to 5.9% in PM10.” However “the variable speed policy reduced NOx and PM10 pollution by 7.7 to 17.1% and 14.5 to 17.3%.” The conclusion is that VSL is more effective at reducing pollution that the fixed speed reduction.

Reference
http://diposit.ub.edu/dspace/handle/2445/44528 (Accessed: April 7 2016)
Potential of variable speed limits for emission and noise reduction on the E313 motorway to Antwerp, Belgium

Summary

Examines the overall effect of VSL on the emissions along a motorway corridor via microsimulation, unusually the report concludes that on this section of motorway the VSL technology makes little difference. Also uses simulation to evaluate other options available including a permeant speed limit reduction to 90kph which produces some small benefits <2% in emissions for a 4.25% decrease in speed.

Reference


Summary results of Dutch field trials with dynamic speed limits (DYNAMAX)

Summary

Analysis and results from five field trials on four locations in the Netherland where VSL was used alongside novel algorithms to adapt the speed limit to suit certain policy requirements. Changes in driving behaviour, traffic flow characteristics, traffic safety, air quality and noise levels were analysed. Of particular interest is the site on the A58 near Tilburg, where the VSL technology was used to improve air quality.

Reference


Using ITS to Reduce Environmental Impacts

Summary

Intelligent Transport Systems (ITS) are usually used to reduce congestion, however the focus of this paper is on how ITS measures might be used to reduce emissions and improve air quality. The paper is “based on data from probe vehicle data for NOx which has subsequently been related to different speed characteristics, and an emissions toolkit based on instantaneous vehicle emission data.”

Reference

E.2 Future development

Due to the large volume of references drawn together for this part of the research only select papers and documents have been fully summarised in E.2.1. If the reference cannot be found in the full summary section then it can be found in general references have been included in Section 8.

E.2.1 Summarised references

Impacts of a Cooperative Variable Speed Limit System

Summary

This study investigated dissemination of VSL to in-car displays via roadside units can bring mild improvements in efficiency and emissions. Microsimulation indicated modest savings of 1.52% in fuel consumption using in-car units to display the VSL in comparison with a contemporary gantry VSL system. The mean speed of the in-car system was lower but no significant increases in overall travel time were observed.

Reference


Cooperative Variable Speed Limit Systems

Summary

Grumert’s thesis builds on their previous work to examine differences between a contemporary VSL system with a cooperative VSL (C-VSL) system which has: the ability to communicate changing speed limits earlier than a traditional gantry system; display individualised speed limits per vehicle determined by their current speed and position; and that individualised speeds can be automatically implemented via integration with cruise control. Novel algorithms for the control of a C-VSL system are formulated by the author and assessed using the SUMO microsimulation software. The results of this comparison between a standard VSL and a C-VSL system indicate that a C-VSL system produces a 9.4% reduction in NOₓ and a 15.3% reduction in hydrocarbon emissions.

Reference


Variable speed limit: A microscopic analysis in a connected vehicle environment

Summary

This paper uses VISSIM microsimulation to evaluate an algorithm formulated by the authors which utilises data from connected vehicles to optimise and control VSL settings. The study optimised VSL setting based on three factors; travel time, safety and fuel consumption. This work compares two different penetrations of connected vehicles of 50% and 100% with a base scenario with no VSL control. The research highlighted that in an environment with 100% penetration of connected vehicles optimising for any of the three factors would produce reductions in collisions, travel time and emissions across the board. However in a lower penetration rate of 50% optimising for fuel consumption or travel time can have a negative impact on collision probability.
Reference

Energy and emissions impacts of a freeway-based dynamic eco-driving system

Summary
Focusing on so called intelligent speed adaption (which operates on a similar principle to VSL but is connected directly to a road user) this study examined the use of an in-car unit to display speed advice to the driver in real time. This advice was calculated based on flows from the existing California Freeway Performance Measurement System (PeMS) which makes use of inductive loops to monitor Freeway traffic. These in-car units helped drivers optimise their speed for emissions and also provided speed data from the car back to the central system. These advisory units produced a 10-20% saving in fuel without a significant increase in the overall travel time in both simulated and real world experiments.

Reference

The impacts of cooperative traffic systems on safety, environment and travel times

Summary
This paper presents the results of the impact assessment study of ten cooperative systems, conducted as a part of the European project COBRA (Cooperative Benefits for Road Authorities). COBRA is designed to provide decision support for road authorities who are investing in cooperative systems and infrastructure. The paper amalgamates and analyses the results of 31 previous studies which looked at the impact of cooperative systems, including field operational trials and simulation. The projects were divided as follows: “Ten V2I/I2V cooperative systems were selected and grouped into three bundles: Local dynamic event warnings, In-vehicle speed and signage and Travel information and dynamic route guidance.” The results are summarised in terms of the indicators for safety, traffic efficiency and environmental impacts against each system bundle. This paper provides a good source for benefits comparisons of different C-ITS systems.

Reference

Improving moving jam detection performance with V2I communication

Summary
This paper investigates an extension to the DYNAMAX project using in-car units and roadside infrastructure to expand the capabilities of the system. The purpose of this paper was to improve the detection speed of the end of emerging queues. The in-car units provided related vehicle position and speed data while providing dynamic speed advice directly to the driver. The performance of the system was assessed using: detection delay; accuracy of the queue tail location; and the accuracy of the length of the queue. The report concludes that the additional data from the cooperative system reduces the average detection delay and improves the accuracy of the end of
queue and length of queue predictions. In a scenario with only 1% penetration of equipped vehicles the detection time is reduced by 1.5 minutes (to an average time of 40 seconds) over a non-cooperative system using inductive loops only.

Reference
Appendix F
Queue Protection and Congestion Management Algorithms – Options for Enhancement

F.1 Current situation
There are two algorithms running in parallel: the queue protection (QP) and congestion management (CM) algorithms. They both provide instruction to drivers (in the form of speed limits) and also information (via messages and pictograms). Speed limits are generally mandatory; advisory signals are only used at locations where there is no CM algorithm, and only QP is active.

The objective of the signalling is to provide signalling that is appropriate for the traffic conditions, and also appears consistent and coherent to drivers. A balance has been sought between responsiveness and not having the signals changing rapidly. The QP system is rapid response; the CM system is heavily smoothed.

The two algorithms do not interact; they both make recommendations for signal settings at each location and the more restrictive speed limit is displayed.

F.2 Possible options
Both algorithms process input data and then output instruction and information to drivers. Changes can potentially be made to the input data (quantity or type), to the output (method or content), or to the processing within the algorithms.

The following section lists possible options, with a brief description of the pros and cons of each. The two algorithms are considered separately, as they currently work independently of each other. A final option considers combining the two algorithms.

The described options could be implemented individually, or a combination could be selected.

F.3 Queue Protection

F.3.1 Do Nothing
The current system is highly responsive, but with a high false alarm rate. Signals can get set due to a faulty sensor, or due to a single slow moving vehicle. One drawback of the current system is that the data that causes an alert is not stored. Therefore, it is not possible to tell whether signals were set due to a sensor fault, or due to a slow vehicle (i.e. the algorithm operating correctly, but possibly setting inappropriate signals).

Pros:
- The algorithm is tried and tested.
- No expenditure required.
- Provides very rapid response.
Cons:
- Reacts to individual vehicles, rather than queues.
- Minimal checking prior to signals being set.
- High false alarm rate.
- No audit trail for alerts.

F.3.2 Use a new algorithm

Other countries have incident detection and queue protection algorithms. There has also been considerable theoretical research undertaken into incident detection.

Incident detection algorithms look for traffic patterns (e.g. longer journey times, lack of traffic downstream, or differences from typical days) to deduce a blockage on a link. Queue protection algorithms detect slow-moving or stopped traffic. The current Highways England system goes even further, detecting and responding to individual slow vehicles.

A policy decision will need to be made regarding the purpose of the algorithm. It can be highly safety-based (as now) or be more focussed on network management (the incident detection algorithms), or various points in between.

Pros:
- Fewer false alarms.
- Information on incidents would be available.

Cons:
- Would need to check that new algorithms were compatible with existing detectors.
- Slower detection times.
- Incident information might not be useful or provide benefits to the signalling.
- Could involve considerable evaluation and testing.
- Expensive.

F.3.3 Introduce additional checks to existing algorithm

The current QP algorithm sets signals when a single slow vehicle is detected. The algorithm could be modified so that additional evidence was needed. Possibilities would include a slow vehicle in another lane, several slow vehicles in a particular lane, or slow traffic detected at two consecutive detectors. Checking for additional slow vehicles at a detector would stop signals coming on for a single slow vehicle (e.g. pulling onto the hard shoulder), and checking additional lanes might reduce the number of alerts from faulty detectors.

Requiring slow traffic at two consecutive detectors would be a bigger functional change – it would provide confirmation of a queue, but at the cost of delaying queue protection signalling by a few minutes.

Pros:
- Fewer false alarms.

Cons:
- Slower detection times (but possibly only by a few seconds).
• Might require evaluation and testing, using real traffic data to simulate alerts.
• Might not stop all false alarms.

F.3.4 Record more information about alerts

This would not directly improve the performance of the algorithm, but it would provide more information about the cause of each alert. It would provide a better understanding of whether the alerts were caused by a sensor fault, or by the algorithm responding as required to a real (but transitory) slow vehicle. This knowledge might help further improvement of the algorithm.

Pros:
• Would obtain a better understanding of why signals are set.
• Audit trail available.

Cons:
• Might not help in improving signalling.
• Would require additional information to be transmitted. Ideally, comprehensive individual vehicle data (IVD) would be transmitted, but as a minimum, full data from the vehicle that caused the alert.

F.3.5 Use speed data directly, rather than occupancy

The concept of queue protection is to set signals based on traffic speeds. When the algorithm was initially developed in the 1970s, speed data was unreliable, so occupancy was used as a proxy for speed. This has several drawbacks, in particular that long vehicles will trigger alerts at higher speeds than cars.

HIOCC2 addressed this problem by adding an additional check on vehicle speed when an occupancy alert was generated. The underlying HIOCC alerts are still generated by occupancy.

Modern detectors are far more reliable regarding vehicle speed, and speed data could be used instead of occupancy. This would remove a level of complexity, and allow extra flexibility in selecting speed thresholds for alerts to be generated. Alerts could be generated based on individual vehicle’s speeds, or from average speeds (either smoothed or unsmoothed).

The radar detectors being rolled out on new schemes emulate the operation of HIOCC2, again adding an extra layer of complexity. Generating alerts directly from speed data would simplify the alert procedure.

Pros:
• Would simplify the alert process.
• Might eliminate some alerts from long vehicles.

Cons:
• Would still not provide an audit trail for alerts.
• Would potentially fail if speed data was not available.
F.3.6 Mitigate effects of false alarms

HIOCC is a rapid response system that sets signals as soon as an alert is generated. An alert from a single vehicle typically clears within 90 seconds (once some higher speed traffic has passed the detector). However, to reduce signal variability, HIOCC settings have a minimum on time of 4 minutes.

This means that off-peak alerts, either from a single vehicle or due to a sensor fault, cause a bank of signals to be set for 4 minutes. This minimum on time could be reduced to 2 minutes. That would reduce the effects of any spurious settings, but might have the side effect of making the signal settings more variable during peak periods. The signals displayed would be appropriate, but drivers might see them changing more frequently. The effects of this change on the signalling could be simulated in advance, using real IVD from congested periods.

Pros:
- Would reduce the disbenefit of false alarms.

Cons:
- Might make signalling more variable in stop-start driving conditions.

F.3.7 Use in-car data as input

Typically, detectors are located at 500m intervals. If a queue forms just upstream of a detector, the queue will need to tail back as far as the next detector before an alert is generated. In peak periods, this will typically happen within 90 seconds, but overnight, it could take considerably longer.

If speed data was available from in-car units, then this could be used to detect queues irrespective of detector locations. At peak times, with 10% of vehicles equipped, data would be received from every location every 6 seconds, with a higher proportion of equipped vehicles giving even better coverage. There might be an issue late at night, when several minutes might pass before an equipped vehicle travelled along the road; during this time, a newly formed queue might go undetected.

In-car data is primarily useful for speed, and would be used to inform the QP algorithm. The CM algorithm runs from flow data, and in-car units would not provide this (unless almost all cars were equipped).

Pros:
- Improved queue detection.

Cons:
- Would need a new algorithm to process in-car data and relate it to signals.
- Might be increased delay in setting signals.
- Would need sufficient equipped vehicles to provide good coverage.
**F.3.8 Run algorithm from the instation rather than the outstations**

Currently, QP alerts are generated from the out-stations, and the in-station then processes the alerts into signal settings. This has the advantage of speed and simplicity, but does not allow the system to have a greater overview of traffic conditions.

The QP alerts are generated by individual vehicles, and the individual vehicle data is not transmitted to the in-station. Therefore, running the existing algorithm (or an enhancement of it) from the in-station would require additional transmission capability. An alternative would be to run queue protection from the 1-minute data, but that would reduce the speed of detection and make the algorithm less sensitive.

Another alternative would be to have the individual alerts generated at the out-stations, but then to have the in-station carrying out further checks and analysis, e.g. whether alerts had been generated in more than one lane or at more than one site. This would also reduce the speed of detection, but would provide greater robustness to the signal settings. The increased time to set signals might only be a few seconds in the case of additional lane checks.

**Pros:**
- Would provide more robustness to the signal settings.

**Cons:**
- Would reduce the speed of detection.
- Might require additional transmission capability. The more complex solutions would require full IVD to be transmitted.

**F.3.9 Output speed restrictions to in-car units**

In the future, in-car cooperative vehicle technology will be capable of receiving speed limit information. This could be provided to the driver, or the in-car systems could limit the car speed to the prevailing speed limit. This could be additional to, or eventually replace, the physically displayed variable speed limit.

**Pros:**
- Would be a more efficient way of communicating speed limit information.

**Cons:**
- Would not address the suitability of the speed limits.
- Systems that restricted cars to the speed limit would need a high proportion of equipped vehicles, to reduce risk of accidents.

**F.3.10 Dampen down signal responsiveness**

The current queue protection signal algorithm provides a highly responsive system, setting and clearing signals as queues build up and dissipate. The signalling could be made less variable, e.g. by setting signals on a link-by-link basis rather than at individual gantries.

**Pros:**
- Potential for less infrastructure to be required.
Drivers might be happier with signals changing less frequently.

Cons:
- Increased delay, especially on long links.
- Drivers would have less information on the location of an incident, so safety might be adversely affected.

**F.3.11 Use alternative method to mandatory signalling**

The QP system currently sets speed restrictions. In a non-SM environment, these are advisory, and are anecdotally not well observed. This is partly because the original advisory settings were manually set, by operators who had little precise information of the problem. Signals were therefore often inappropriate.

In SM environments, the QP signalling is mandatory, and is generally well observed. The drawback of this is that when there are false alerts, traffic is slowed unnecessarily, this causes delay and driver irritation.

An alternative would be to use messages and pictograms for queue protection, and only use mandatory signalling for congestion management. This would mean few speed limits set during off-peak periods (only by operators in response to on-road events).

Pros:
- Reduced delay from false alarms.
- More informed drivers, with heightened awareness.

Cons:
- Some safety benefits could be lost, as speeds might be higher.

**F.3.12 Disable signal settings within queues**

This is Option 2 from the Options Report entitled “Review of the Variable Message Sign and Signal Setting”. Drivers have reported dissatisfaction from sitting in queues with 40mph limits being displayed, as they think that a speed limit should be achievable. Signals could be switched off in queueing conditions, and messages used to inform drivers of any delays.

This would only be a cosmetic change, and would have a number of drawbacks. A minor one would be how to switch the signals off. If they just went blank, then the previously displayed speed limit would technically still need to be cancelled, and displaying a roundel when there is queueing traffic has already proved to be highly unpopular with drivers. A further drawback would occur in stop-start driving conditions. When drivers started to speed up, it would be necessary to switch the signals back on for safety reasons. This would be likely to be unpopular with drivers. The alternative of leaving the signals off as drivers accelerated would have an adverse impact on safety.

Pros:
- Increased driver satisfaction in incident conditions.
- Increased information to drivers.

Cons:
- Only a cosmetic change.
- Increased driver irritation in stop-start conditions (or reduced safety).
- Complex to implement.

**F.3.13 Use additional signal settings**

This is Option 4 from the Options Report entitled “Review of the Variable Message Sign and Signal Setting”. The principle is similar to Option 2 of the report – to increase driver satisfaction in queues. 20mph signals would be displayed in queueing conditions, as this is a more appropriate speed limit.

**Pros:**

- Increased driver satisfaction in incident conditions.

**Cons:**

- Only a cosmetic change.
- Might detract from manual 20mph signalling that is set in extreme circumstances.

**F.3.14 Public education**

This is Option 5 from the Options Report entitled “Review of the Variable Message Sign and Signal Setting”. This option is to provide more publicity and information on why signals become set.

**Pros:**

- Increased driver satisfaction.

**Cons:**

- No actual change.
- Might be difficult to reach the correct target audience.

**F.4 Congestion Management**

**F.4.1 Do Nothing**

The current system relies on the capacity of the road being relatively constant. There are known bottlenecks on the network that are recurrent seed points of flow breakdown, at which capacity is known to be lower than elsewhere. However, the capacity can vary considerably according to weather conditions, time of day, day of week and seasonality. The current algorithm only allows one set of thresholds per site, which has to be optimised for the whole range of capacities at that site.

The original objective of CM schemes was to delay the onset of flow breakdown, by smoothing the traffic as flow levels approached capacity. It has been found that at many locations, demand flows far exceed the capacity, and congestion is inevitable. The benefits from delaying flow breakdown by a minute or two are minimal. Greater benefits are achieved by controlling traffic at the ends of peak periods, as it starts to recover. Smoothing the traffic allows the shockwaves to dissipate quicker. However, any journey time benefits are offset by additional delay from speed limits being set at the shoulders of the congestion.
There is flexibility within the algorithm to cater for site specific issues. These could be physical (e.g. bends or gradients, or road markings) or sensor-related (e.g. sensors providing different counts). Separate thresholds can be assigned to each site.

Pros:
- The algorithm is tried and tested.
- No expenditure required.
- Provides benefits at the shoulders of the peak periods.
- Flexibility of settings from site to site.

Cons:
- Settings are often a compromise, and not particularly suitable for the prevailing traffic conditions.
- No predictive capability.

**F.4.2 Use a new algorithm**

While several other countries have QP or incident detection systems, very few have a CM system. There are no real tried and tested alternatives. An entirely new algorithm would be likely to be self-learning, and to have some predictive capability.

Pros:
- Would be able to develop a more efficient system.

Cons:
- Would need extensive evaluation and testing.
- Expensive.

**F.4.3 Link-based signalling**

The current algorithm is heavily smoothed, so that CM signals do not often change state. This was in response to driver feedback that they did not want rapidly changing signalling. The signalling could be further smoothed by setting signals on a link-by-link basis, rather than at individual gantries.

However, this is currently the default setting. When a system is optimised, thresholds are initially set to be the same along a link, and this is only varied if there is a change in capacity along the link, e.g. due to a heavily used junction at one end.

Pros:
- Potential for less infrastructure to be required.
- Drivers might be happier with signals changing less frequently.

Cons:
- Increased delay, especially on long links.
- Drivers would not see a need for the settings on some on the link.

**F.4.4 Different thresholds for time of day**

Capacity is constantly changing, depending on a variety of factors. One of these factors is the movement of traffic. Traffic joining the motorway causes the most lane changing, and therefore causes a reduction in capacity. Some junctions have greatly different capacities in one peak period.
(when traffic is joining the motorway) to the opposite peak period (when traffic is leaving the motorway). The current algorithm only allows a single set of thresholds, which have to be selected to provide a balance between the peak periods. The appropriateness of the signalling is therefore compromised.

Having a separate set of thresholds for mornings and evenings would mean that signalling would be more appropriate. This would require changes to the algorithm and also to the structure of site data.

When CHARM is introduced, this option would be likely to be more viable, as the different thresholds could be communicated to the outstations without the need for changing the structure of site data.

Benefits would arise from more appropriate signalling. The benefits would come from increased driver satisfaction, reduced journey times (if signals are currently displayed when not needed) and reduced congestion (if signals are currently not on in time).

Pros:
- Signalling would be more appropriate to the traffic conditions.
Cons:
- Would need evaluation and testing. Site data would need to be redesigned, and this and all of the associated programs would need to be tested.

F.4.5 Different thresholds for time of year

Capacity varies according to seasonality. The capacity during the summer months is higher than in winter. Ideally, the thresholds for the summer would be higher, so that signalling came on later in the summer months. Benefits would arise from more appropriate signalling, as described in Section F.4.4.

This change would not require a change to the structure of site data. Two sets of site data would be required, that could be swapped in and out at suitable times of the year. In the past, this has been difficult to achieve due to requirements for site data testing. However, a procedure has been developed for swapping sets of site data when All Lane Running (ALR) is activated, that could also be used to introduce seasonal thresholds.

Pros:
- Signalling would be more appropriate to the traffic conditions.
Cons:
- Would possibly only be a small benefit.

F.4.6 Weather dependent signalling

The single set of thresholds has to apply for all weather conditions. Logically, the capacity of the road should be lower in poor weather, due to drivers leaving longer headways. Signals that came on earlier during poor weather conditions would help to manage the traffic better. Benefits would arise from more appropriate signalling, as described in Section F.4.4.
Real-time weather information is available, but this would need to be fed into the algorithm, which would need to be changed to cater for a variety of conditions. However, initial research has indicated that the change in capacity in poor weather is not as great as previously thought.

Pros:
- Signalling would be more appropriate to the traffic conditions.

Cons:
- Would possibly only be a small benefit.
- Would require several changes to cater for weather information.

**F.4.7 Introduce predictive capability**

Traffic patterns on particular day types are relatively consistent. Day types are different days of the week (often with Tuesday to Thursday combined), with allowances for bank holidays, school holidays etc. Currently, the system runs entirely from flow data, with no knowledge of previous days. The system could be modified to use a previous day type’s signalling as a basis for the current day. Flow levels between days could be compared to predict when flow breakdown was likely to occur.

Congestion levels elsewhere on the network could also be used to predict the congestion likely to be experienced on the motorway in question.

Benefits would arise from more appropriate signalling, as described in Section F.4.4.

Pros:
- Signalling would be more appropriate to the traffic conditions.

Cons:
- Would possibly only be a small benefit.
- Would require extensive changes to the algorithm.

**F.4.8 Run algorithm from the in-station rather than the out-stations**

Currently, CM alerts are generated from the out-stations, and the in-station then processes the alerts into signal settings. This has the advantage of speed and simplicity, but does not allow the system to have a greater overview of traffic conditions or of external influences such as weather.

The CM alerts are generated by flows increasing and/or speeds dropping, based on 1-minute smoothed data. This data is transmitted back to the in-station, together with the alerts, so there is an audit trial for CM alerts (unlike the QP alerts). Alerts from a site set a predefined set of signals.

Running the CM algorithm from the in-station would allow some additional checks to be made, e.g. that flow levels were consistent from site to site on a link. However, this would not particularly enhance the signalling. Sensors are tuned prior to activation of CM, and any faulty sensors are disabled. The remaining sensors on the link will provide suitable signalling, as flows are consistent along a link.

Running the algorithm from the in-station might be necessary for some of the improvement options discussed above:
- Different thresholds for time of day. It might be necessary to run this from the in-station. The outstations have access to the current time, but it is not known whether this would be available to the algorithm.
- Different thresholds for time of year. This could still be run from the out-stations, as it involves a replacement of site data.
- Weather dependent signalling. This would need to be run from the in-station, as weather data would not be available at the out-stations.
- Introduce predictive capability. This would need to be run from the in-station, as a comparison with historical data and/or conditions elsewhere on the network would need to be made.

Pros:
- Could provide more information to enhance the appropriateness of the signal settings.

Cons:
- Might not be necessary, depending on the options selected.

F.4.9 Ramp management

Although not strictly part of the CM algorithm, ramp management is another means of managing congestion. The current ramp metering system provides small benefits, but it is limited by the fact that the overall flows onto the motorway remain the same, and traffic can only be held on the entry slip roads for a few minutes before having to be released (to avoid problems on the surrounding network).

The concept of Smart Junctions has recently been suggested for some M25 junctions. This would enable signalling on the all-purpose network to be modified to control flows onto the motorway. A more extreme version would be full ramp management, which would involve closing entry slip roads for a period of time, possibly for up to 2 hours during peak periods. As merging traffic is the main cause of congestion on the motorway network, this would have substantial benefits for traffic on the motorway, but at the cost of more traffic on the all-purpose network.

Pros:
- Would reduce congestion on the motorway network.

Cons:
- Would increase congestion on the all-purpose network.

F.5 Combine Algorithms

F.5.1 Combine QP and CM algorithms

The QP and CM algorithms run off the same basic data – the raw traffic data of speed, flow and occupancy. The QP algorithms run from the raw data and the CM algorithms from 1-minute smoothed data. There may be some benefits from combining these algorithms. This is Option 3 from the Options Report entitled “Review of the Variable Message Sign and Signal Setting”.

Combining the algorithms might assist in distinguishing between slow-moving vehicles, either individually or in platoons, and full queueing behaviour. This option would have a similar effect to adding additional checks to the QP algorithm.
In the wider sense, the two algorithms are already combined in that they co-exist. The signal settings from each are combined before display, with the most restrictive signal setting at each gantry being the one displayed. The functionality of the signalling has been modified in a few cases to provide better overall signalling. An example is the CoMo40 setting in the West Midlands, where the QP algorithm sets 40mph signals, then the CM algorithm keeps them on in stop-start driving conditions.

Pros:

- Could provide more appropriate signalling, especially when there are only a few slow vehicles.

Cons:

- Might result in some unprotected queues.
- Would need evaluation and testing, to determine whether the projected signalling would be appropriate for the traffic conditions (both for queue protection and congestion management).