Ramp Metering System

Requirements Specification
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1 BACKGROUND AND CONCEPT OF RAMP METERING

Ramp metering is a traffic management technique which regulates the number of vehicles allowed to join a motorway at peak periods. The purpose of the system is to prevent or delay the onset of flow breakdown on the main carriageway by a combination of:

- Restricting the flow onto the motorway of additional traffic that, if unrestricted would trigger flow breakdown, and
- Managing the flow on the entry slip road to avoid large platoons of vehicles entering the main carriageway and causing flow breakdown.

By preventing or delaying flow breakdown the system provides the following benefits:

- Less congestion and improved traffic flows
- Higher throughput during peak periods
- Smoother and more reliable journey times
- Reduced risk of accidents
- Environmental improvements as a result of noise reduction and improved fuel consumption.

The system uses part-time traffic signals on the slip road which come into operation when traffic sensors on the main carriageway indicate heavy traffic.

2 OBJECTIVES AND APPROACH FOR THIS PROJECT

The deployment of this system follows extensive trials of ramp metering on the M6 around Birmingham and the M3/M27 in the south of England. These trials established that benefits could be produced in certain circumstances determined by the flows on the main carriageway and slip road, and the physical characteristics of the junction. For these reasons, ramp metering will not be suitable for all motorway junctions, however it is likely to be deployed on a large number over the next few years. This project is the first phase of that deployment and the Highways Agency urgently requires some ramp metering systems implemented by March 2006, with a rolling programme of the remainder installations over the following 12 months.

The benefits were found to be sensitive to the nature and calibration of the control algorithm. Since the UK trial system was installed, a number of algorithms have been developed and tried around the world. Some may be suitable for use in the UK others may not. It is therefore the intention of this project to quickly deploy a number of systems using simple algorithms then, once operation is established, to optimise the performance of ramp metering in the UK by evolving the system to incorporate more complex algorithms. It follows that there are two fundamental requirements for this system:

- It shall be developed and deployed quickly
- It shall be easily enhanced, extended and modified through evolution.

The Highways Agency is therefore seeking a system that can be modified, can have new algorithms added, and can be enhanced without necessarily having to refer back to the original designers and programmers. The system specified in this document should therefore be considered a platform for algorithm and functional development and not a production unit of stable design.

For simplicity of development and hence to reduce timescales, ramp metering is being specified in the first instance as a stand alone system. It is however part of a suite of traffic management techniques which will form part of integrated traffic management schemes of the future. Such schemes will see interaction between individual ramp metering sites and:

- Adjacent junctions with ramp metering, thereby providing co-operative algorithms
- A control centre enabling motorway-wide coordination
- Traffic signals on the junction and all purpose road network surrounding the junction
- Controlled motorways where speed regulation is used to prevent shock waves and flow breakdown on the main carriageway
• High occupancy or designated vehicle lanes.

This is another reason why the system supplied as part of this contract must be expandable to accommodate the hardware interfaces, software and processing power to deal with these additional features and functions.

3 SYSTEM CONCEPT

This specification is written with the purpose of defining the minimum functional requirements to perform ramp metering, specified in such a way as to give contractors maximum freedom in the way those requirements are implemented.

The proposed system is shown diagrammatically in Figure 11 and comprises:

1. A ramp metering controller (RMC)
2. An upstream traffic sensor (MIDAS outstation)
3. A downstream traffic sensor (MIDAS outstation)
4. Traffic signal heads
5. Slip road traffic sensors
6. Loop interface unit
7. Communications to and from the RMC
8. Cabling to interconnect these parts and mains power supply.

The RMC is the roadside intelligent controller which gathers information from the sensors, performs the ramp metering algorithms and controls the signal heads. The RMC may be similar to, or incorporate a traffic signal controller, or be a new design at the discretion of the contractor. The RMC will be provided with a communications link, possibly using the internet so that, with suitable security arrangements, supervisory functions can be carried out from a variety of locations. It will operate stand-alone for an indefinite period if communications fails or does not exist, however it will normally be able to communicate so that it can be supervised, configured and its performance evaluated both locally and remotely.

The main carriageway traffic sensors will be standard MIDAS outstations, making use of existing outstations where they exist or installing new ones where needed. The MIDAS outstation auxiliary link (OAL) will be used to feed data to the RMC alongside the normal data flow from MIDAS. There may be more than one MIDAS outstation connected to each of the links (upstream and downstream), though only one will be selected for use in each case. Spare pairs in the existing motorway communications infrastructure longitudinal cable will be used to bring the connections back to a suitable access for the RMC.

A stop line will be placed on the slip road with traffic signals at both ends of this line. Standard traffic signals (with an oval yellow backing board) will be driven from the RMC. In addition to the usual signal heads, a second pair will be mounted lower on the pole and angled towards drivers waiting at the stop line, thus avoiding the need for a separate secondary signal which may confuse drivers in a non-junction setting.

Loops along the length of the slip road from the slip road entrance to the stop line shall provide information to the RMC enabling it to manage the slip road queue. Special action (queue override) is taken if the queue reaches the loops nearest to the slip road entrance. There shall be provision in the RMC for up to 10 sets of loops normally installed at intervals of 50 metres along the slip road. Hence because of the distances involved, provision will be made in the infrastructure design for a loop interface unit to overcome the distance limitation on loop tails. Contractors may offer alternative solutions to overcome the distance limitation on loop tails, which will be considered if provided early enough in the programme to be incorporated into the infrastructure design.

To provide a simple operational interlock with other equipment on-site (for example a warning VMS) the RMC shall generate a signal indicating its intention to commence metering operations. The RMC shall only commence metering operations if an input signal is activated. Deactivation of this input signal at any time shall shut metering down using the specified shut-down sequence.

4 SCOPE OF SUPPLY

The contractor shall provide, in accordance with the bill of quantities:

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1. Development, design, integration and project management (of the items described in this specification to produce a ramp metering system)
2. Ramp metering controllers including application software and Human Machine Interface (Supervisory interface)
3. Loop interface units (if required)
4. LED signal heads
5. All interconnecting cabling with the exception of power, loop tails and existing longitudinal
6. Installation and commissioning services on-site
7. Maintenance services
8. Design, operational and maintenance documentation
9. Operational and maintenance training.

The infrastructure, designed and implemented by others will provide:
1. Inductive loops for vehicle detection
2. Roadside enclosure for the ramp metering controller
3. Roadside enclosure for the loop interface unit (if required)
4. Buried ducts to carry cables
5. Mounting poles for signal heads
6. Fixed warning signs in advance of the stop line
7. Power supply to the ramp metering controller in the form of single phase mains supply
8. Communications to/from the ramp metering controller through a remote connection
9. MIDAS outstations where additional needed.

5 RAMP METERING CONTROLLER
The Ramp Metering Controller and its interfaces are shown in Figure 12. Any diagrams in this specification are provided to aid understanding of the requirements. They should not be considered to provide a full and complete representation of the functional requirements expressed in the text.

5.1 FUNCTIONAL REQUIREMENTS

5.1.1 Operational Modes
The RMC shall operate in one of 5 operational modes, illustrated in Figure 13, and in accordance with the algorithm specification:
1. Standby
2. ‘Switching On’ State
3. Steady State
4. Queue override
5. ‘Switching Off” State.

When power is applied, the RMC shall initialise itself into standby mode. The signal heads must not be activated at any point during initialisation.
In standby mode, the RMC shall continuously collect, filter and analyse input data (for all MIDAS outstations and all Queue Management loops) and regularly evaluate the switch on/off algorithm. The signal heads shall remain inactive.

If and when the switch on-off algorithm sets the desired release rate to below the ramp metering free flow release level, as part of the “Switching On” state, the RMC shall activate the RM_Active_Request signal. If the RM_Enable signal is on, the RMC shall proceed through the “Switching On” state, activating the signal aspects accordingly. If the RM_Enable is off it shall remain in standby mode.

Upon completion of the start-up sequence, the RMC shall enter normal operation (“Steady” state).

In normal operation, the RMC shall continuously collect, filter and analyse input data (for all MIDAS outstations and all Queue Management loops) and regularly evaluate all algorithms, activating the signal aspects accordingly.

The time periods for the algorithms will generally be different (typically longer) than the cycle times for the signal aspects and they will not be synchronous. Therefore it is likely that there will be two or more signal cycles for any one algorithm period. Therefore, in normal operation the RMC must apply the signal timings from the last Release Level until a new Release Level (or a Queue Override or shut-down sequence) is applied.

If queue override is triggered then the queue override algorithm shall demand a high release rate (up to the free flow level) for a defined period of time. This shall be followed by a period during which the queue override is briefly inhibited to allow the ramp queue to stabilise. Once the RMC has completed an iteration it shall return to normal operation.

If and when the switch on-off algorithm sets desired release rate to above the ramp metering free flow release level, as part of the “Switching Off” state, and upon completion of the current cycle of normal operation, the RMC shall commence its shut-down sequence, returning to standby when the signal heads will be inactive.

If at any stage the RM Enable signal is turned off then, upon completion of the current cycle of normal operation or queue override, the RMC shall commence its shut-down sequence. Upon completion of the shut-down sequence it shall set the RM_Active_Request to off and, return to standby when the signal heads shall be inactive.

5.1.2 Activation Modes

Using the supervisory interface (described later) it shall be possible to configure a set of timed activation periods.

The RMC will provide at least 4 different timed activation periods for each day of the week (ie 28 potentially different ‘on settings’ and 28 potentially different ‘off settings’ per week).

Using the supervisory interface it shall be possible for a supervisor to select one of the following activation modes:

1. Locked standby (Manual Override = Off) – the system shall remain in standby regardless of the results of evaluating the ‘automatic’ elements of the switch on-off algorithm
2. Manual on (Manual Override = On) – the system shall enter normal operation (and if necessary, queue override) via the “Switching On” state regardless of the results of evaluating the ‘automatic’ elements of the switch on-off algorithm
3. Auto (Manual Override = Auto) – the normal means of automatic activation based on the results of evaluating the following ‘automatic’ elements of the switch on-off algorithm:
   a. Queue presence switching
   b. Speed switching
   c. Flow and Occupancy switching
   d. Time switching

The operation of these elements is further described in section 6.

In all cases, the RMC will react to changes to the activation mode using the logic described in section 5.1.1 above and using the appropriate start-up and shut-down sequences.
5.1.3 Algorithms
The RMC shall activate the signal head aspects in accordance with the filtering and algorithms described in section 6 and illustrated in Figure 14.

The RMC shall initially provide two main carriageway algorithms, Demand Capacity and ALINEA, with the ability for a supervisor to switch between the algorithms.

In all cases when algorithms become the one in use they shall start with their default settings.

Algorithms not in use shall continue to be evaluated as if they were in use so that their potential performance can be compared with the algorithm in use by a supervisor (see data logging below).

The Algorithms shall have the capacity to deal with up to 4 lanes on the main carriageway (hence 4 loop pairs upstream and 4 loop pairs downstream), and up to 10 loops on each of 2 lanes on the slip road.

5.1.4 Configurability
All constants shall be configurable at any time by the supervisor between their minimum and maximum values stated. Once configured they shall be non-volatile in the event of indefinite mains power failure.

It shall be possible to configure the algorithms to ignore loops which are not connected or not used as a result of fewer lanes or shorter slip roads (hence requiring less than 10 loops per lane on the slip road). It would be preferable if this were automatically sensed.

Where more than one MIDAS outstation is connected to the upstream and downstream links, it shall be possible to configure the address of the one MIDAS outstation to be used on each link.

It shall be possible to configure the RMC for the case where both upstream and downstream outstations are on the same link.

5.1.5 Data logging
The RMC shall provide a data logging facility as described below. The purpose of the data logging facility is to provide sufficient data to enable off-line analysis of the performance of the system and its algorithms. This specification for data logging is therefore a trade-off between resolution (number of variables and sample frequency) and volume of data. The data shall be retrieved either locally or remotely over the communications link using the supervisory interface also described below.

The filters and algorithms each have their own time periods (ie frequency of evaluation). These time periods are independently configurable and asynchronous. Therefore, in order to simplify data logging the RMC shall continuously log the average value of at least 70 selectable parameters and variables (selectable from the inputs to, outputs from and parameters used in the algorithms) over time period $T_{LOG}$.

$T_{LOG}$ shall be configurable between 1 and 60 minutes in steps of one minute.

The RMC shall have the minimum capacity to log the data specified above at one minute intervals for a minimum duration of 31 days of continuous operation.

When the data logging capacity has been reached, the RMC shall continue recording data whilst simultaneously discarding the oldest data to make room on a first-in first-out basis.

The RMC shall log the exact time that ramp metering is activated and the exact time it is de-activated for each occasion over the previous 31 days.

Alternative methods of data logging that will meet the stated purpose can be proposed by the contractor and will be considered.

5.1.6 Fault monitoring and diagnostics
The RMC shall provide two levels of fault detection and reporting, and react to them as follows:

A ‘fault’ is an indication of degraded performance, however not of sufficient magnitude to prevent ongoing ramp metering. When a fault is detected, the RMC shall generate an alert to a remote location. The alert shall briefly describe all current faults, their type (ie critical or not) and highlight the new one.
A ‘critical fault’ is a problem of sufficient magnitude to immediately shut down ramp metering in order, for example, to avoid the display of confusing information to drivers. If at any stage, and in any operational mode, the RMC detects a critical fault, the RMC shall

- Turn off all signal heads within 500 milliseconds and turn off the RM active request signal
- Send an alert to up to three supervisor configurable locations. The alert shall briefly describe all current faults, their type (ie critical or not) and highlight the new one.

The RMC shall keep a copy of all fault alerts sent up to a maximum of 1000 messages. When this capacity has been reached, the RMC shall continue recording alerts whilst simultaneously discarding the oldest messages to make room on a first-in first-out basis.

The RMC shall provide a means of monitoring the aspects being displayed on the signal heads which is independent of the system software. If this mechanism detects that incorrect combinations of aspects are being displayed it will immediately report a critical fault.

The RMC shall provide a means of red lamp monitoring. If one red lamp is found to be faulty a fault shall be raised. If two or more red lamps are found to be faulty a critical fault shall be raised. Similarly, if there is a failure of the red lamp feed or of the red lamp monitoring equipment then a critical fault shall be raised.

Where loop fault information is available to the RMC it shall monitor it, modify the algorithm behaviour accordingly and raise a fault if any loop is reported to be faulty.

The RMC will provide a range of diagnostics and internal monitoring commensurate with modern electronic systems which shall raise faults or critical faults according to the nature of the problem detected.

5.2 INTERFACE DEFINITIONS

5.2.1 Slip Road Loops

The RMC will provide inputs for up to 10 loops on each lane on the slip road (for example: 10 positions, 20 loops for a two lane slip road; as shown on Figure 11).

These loops will be installed by others to Highways Agency specification MCH 1540 unless otherwise agreed.

The contractor shall ensure that occupancy and flow can be measured for slow moving (near stationary) vehicles to a level of accuracy and resolution suitable for use in the algorithms.

The contractor shall ensure that the detection equipment is able to accommodate a range of inductances due to the varying lengths of feeder cable.

Given a limitation of 200 metres from loops to their associated electronics, and depending on the geometry of the slip road and layout of equipment some or all of the loops may be within 200 metres of the RMC, some of the loops may be further away. Therefore to provide maximum flexibility in the site layout:

The RMC shall accept loop inputs directly or via the loop interface unit in any combination. So for example (for a two lane slip road):

- 20 loops could be fed directly into the RMC if all were within 200 metres. The loop interface unit would not be necessary. OR
- Some loops could be fed directly into the RMC and those more distant would be fed into the loop interface unit. OR
- 20 loops could be fed into the loop interface unit if all were within 200 metres of it and the RMC were more distant.

The loop interface unit shall provide the information from the loops to the RMC.

The loop interface shall be able to be located up to 500 metres from the RMC.

Depending upon the design put forward by the contractor, the loop interface unit may either derive power from the RMC or be provided with mains power.
5.2.2 MIDAS Interface

The RMC shall communicate with the upstream MIDAS outstation and the downstream MIDAS outstation using their outstation auxiliary link (OAL).

The MIDAS outstation and OAL are defined in Highways Agency specification TR 2146 and TR 2169; however the contractor is responsible for ensuring the RMC communicates with the MIDAS outstation using the communications protocols as currently implemented on MIDAS outstations.

The RMC shall continuously take all the ‘vehicle data’ that is available from the OAL links then process it according to the filtering and algorithms specified in section 6.

5.2.3 Signal head

The RMC shall provide the necessary signals and power to the signal head, specified in section 6 below, to activate the aspects.

The RMC shall receive information from the signal head in order to determine red light failures, ambient light levels and the display of incorrect aspect combinations.

The RMC shall dim the signal head aspects according to ambient light and in accordance with TR2210.

A switch shall be provided in the RMC to immediately remove the power supply to all signal aspects without interfering with the supply to the controller operating circuits. This switch shall be readily accessible via access to be agreed with the infrastructure cabinet provider. When the power supply is restored to the aspects, the controller will check the RM_Enable signal in accordance with 5.1.1 above, prior to entering the switch-on sequence.

5.2.4 Interlocking with external devices

The RMC shall provide an input (RM_Enable) and an output (RM_Active_Request) as a means of interlocking with external devices driven by the Switch On-Off Algorithm. It is envisaged that if no external devices exist, external links will feed the RM_Active_Request back into the RM_Enable.

The RM_Enable input, when active, enables the RMC to enter and continue to meter traffic onto the main carriageway. The RM_Enable input shall:

- Be a pair of terminals capable of sensing an open or closed contact connected to them (ie clean contacts)
- Be protected against voltages of up to 250v ac being applied in error
- Sense a closed circuit as ‘active’, ie enable ramp metering and an open circuit as ‘inactive’, ie disable ramp metering.

The RM_Active_Request output, when active, indicates the desire by the RMC to commence and continue to meter traffic onto the main carriageway. The RM_Active_Request output shall:

- Be a pair of terminals presenting either an open or closed voltage free circuit (ie clean contacts)
- Be protected against voltages of up to 250v ac being applied in error
- Present a closed circuit as ‘active’, ie ramp metering requested and an open circuit as ‘inactive’, ie ramp metering not requested or power is absent from the RMC.

The RMC will provide four further outputs, RM_ON, RM_Q1, RM_Q2 and RM_Q3. These outputs shall:

- Be a pair of terminals presenting either an open or closed voltage free circuit (ie clean contacts)
- Be protected against voltages of up to 250v ac being applied in error
- Present a closed circuit as ‘active’ and an open circuit as ‘inactive’.

RM_ON shall be active whenever RM_Active_Request is active. Activation of RM_Q1, 2 and 3 shall provide a progressive indication of queue length on the slip road. RM_Q1 shall be active when the length of the queue reaches a predetermined condition. As the queue extends further, RM_Q2 shall become active when a second predetermined condition occurs. When RM_Q2 is active, RM_Q1 shall also remain active. RM_Q3 follows the same logic for a subsequent extension of the traffic queue. RMQ1 and RM_Q2 remain active when RM_Q3 is active.
5.2.5 **Supervisory Interface**

The purpose of the supervisory interface is to allow a human operator (supervisor or user) to perform the following actions:

- Configure constants and parameters that determine the performance of the system
- Monitor performance of the system
- Obtain and transfer data that has been logged by the system to the supervisor’s PC (uploading data)
- Switch between algorithms.

The supervisor may be local, to the RMC or remote. The RMC will be provided with a connection to the internet to facilitate remote supervision. Therefore:

- The RMC shall connect to an asymmetric or symmetric digital subscriber line providing a minimum bandwidth of 512kbps, or such alternative communications link as may be agreed.
- The supervisor shall be able to communicate with the RMC either locally or over the communications link using an industry standard personal computer and minimal additional or specialist software, for example using a standard web browser as the means of interacting with the RMC.

Given that there will be many RMCs installed around the motorway network and all with a remote connection, there shall be a means to individually identify and address each RMC.

The supervisory interfaces (both local and remote) of the RMC will be provided with security to protect against use and disruption by unauthorised personnel, hackers, worms and viruses.

The RMC shall provide two levels of security access to the supervisory interface:

- A password of at least 8 digits will be required to monitor the performance of the system and upload data
- A further password of at least 8 digits will be required to configure constants and parameters and to influence the operation of the system in any way (including installation of new software).

Once configured these passwords shall be non-volatile in the event of indefinite mains power failure.

Each RMC shall support up to 10 individual users each with their own password. For clarity, the RMC need not support access by multiple users simultaneously.

The RMC shall automatically log out inactive users after a configurable time period between 5 and 60 minutes.

It shall be possible for users to select and modify their own passwords.

It shall be possible, under well controlled and very secure circumstances, to reset all passwords to a default setting.

5.2.6 **Configuring constants and parameters**

In near real time, the supervisor shall be able to read and modify constants and parameters described in the algorithm specification.

The supervisory interface shall provide a means by which a supervisor can back-up all configurable items in the system to a file on the supervisors personal computer. There shall be a means to restore back-up data to the RMC.

5.2.7 **Monitoring performance of the system**

The supervisor shall be presented with one or more ‘mimic screens’ illustrating, in near real time, and in an easy to interpret diagrammatic form, the current status of the system. This shall take the form of an overview screen with further detail provided by ‘clicking though’ / ‘drilling down’ to further screens. These screens shall provide a graphical and numeric representation of, as a minimum:

- The current operational status of the RMC including inputs, outputs, algorithms and key intermediate parameters
- The presence of any current faults and/or critical faults
Diagnostic information

Uploading data that has been logged.

The supervisor shall be able to upload selected portions of the logged data for off-line review and analysis. The data will be provided in a form that can be easily loaded into Microsoft Excel (e.g., CSV files).

The supervisor shall be able to upload for review a record of messages sent indicating faults and/or critical faults. It shall be possible to upload them into Microsoft Outlook or Word or Excel.

The supervisory interface shall provide a simple acknowledgement message which shall be sent when a request is received over the supervisory interface. The purpose of this is to enable a remote device to regularly monitor the communications channel to the RMC and establish that:

- The RMC is operating
- Communications is working.

5.3 INTER-UNIT CABLELING

To ensure compatibility with the supplied equipment, the contractor is required to provide interconnecting cabling between the RMC, the loop interface unit and the signal heads. The cable lengths will be determined in consultation with the infrastructure designer.

The cables shall be suitable for pulling through and use inside 100mm cable ducts used by the Highways Agency (which are known to fill with water on occasions).

5.4 FUTURE CAPACITY REQUIREMENTS

Upon delivery of the RMC meeting all the requirements of this specification, and under all operating conditions:

- the software and constant data shall occupy less than 50% of the installed non-volatile memory and
- the transient data shall occupy less than 50% of the volatile memory
- the system shall operate using no more than 50% of available processor bandwidth.

5.5 REQUIREMENTS FOR EVOLUTION AND ENHANCEMENT

For the reasons described earlier, the system requirements and functionality required by this specification are only a small proportion of the eventual requirements for a ramp metering system. Further capacity, software, hardware interfaces and communications will be needed to make ramp metering part of the envisaged integrated traffic management regime of the future.

It is therefore an essential requirement that the RMC can be further developed and enhanced with the addition of hardware interfaces, additional more complex algorithms, features and functionality which are either not yet in a position to be specified or considered complex enough to delay this initial deployment. It is recognised that contractors cannot design and size their system for as yet unspecified requirements, so to address future needs it is an important requirement now that:

- The RMC shall be implemented using an industry standard architecture that is non-proprietary and expandable in terms of hardware interfaces, processing power and memory using components that are readily available and likely to remain so for at least 5 years
- The RMC shall be implemented using, for the most part, a highly developed modular and building block approach to hardware and software development
- The RMC shall be implemented using a software development environment that is readily available to others and that minimises the skills and training needed to modify and enhance the system functionality.

5.6 MOUNTING AND PACKAGING REQUIREMENTS

The RMC and loop interface units will be accommodated in HA approved roadside enclosures. Unless agreed otherwise, a Highways Agency type 600 cabinet to specification MCX0156 will be provided as part of the infrastructure.
Each RMC cabinet will be provided with 100mm cable ducts to:

- The signal heads
- Loop interface unit
- ‘Tapping-off’ point in the longitudinal
- Local loops on the slip road
- Mains power supply.

The Loop Interface Unit cabinet will be provided with 100mm cable ducts to:

- The RMC
- Local loops on the slip road
- Mains power supply if required.

The mains power supplies will incorporate isolation in the base of the cabinet.

Unless agreed otherwise, the cabinets will incorporate 19 inch rack to accommodate the RMC.

Any further terminal rails, terminals and interfacing equipment shall be provided by the contractor.

### 5.7 POWER SUPPLY

The RMC (and loop interface unit, if applicable) shall operate from a single phase mains supply as described in Part III of TR 1100 (General Specification for Motorway Signs, Signalling and Communications Equipment).

In the event of a mains supply failure, the RMC (and loop interface unit, if applicable) shall shut down without malfunction. On restoration of the mains supply they shall commence operation as specified in section 5.1.1.

All exposed conducting materials and components shall be bonded to earth.

### 5.8 ENVIRONMENTAL REQUIREMENTS

The RMC shall meet the requirements of TR 2130 and Part III of TR 1100.

### 5.9 ELECTRO-MAGNETIC COMPATIBILITY REQUIREMENTS

The RMC shall meet the requirements of BS EN 50293 (Electromagnetic Compatibility Road Traffic Signal Systems Product Standard).

### 6 RAMP METERING ALGORITHMS

#### 6.1 INTRODUCTION TO ALGORITHMS

The function of ramp metering is to monitor the traffic conditions and regulate the traffic flow on the ramp onto the main carriageway. Seven general groups of algorithms are used to fulfil this function:

- Release Algorithm
- Arbitration Algorithm
- Switch On-Off algorithm
- Ramp Metering algorithms
- Queue Override algorithm
- Queue Management algorithms
- Data Filtering and Fault Management algorithms

The Release Algorithm shall set the traffic signal timings appropriately to provide the required traffic flow released from the ramp.

The Arbitration Algorithm shall compare the outputs from the various other algorithms as detailed below and determine the required traffic flow to be released by the Release Algorithm.
The Switch On-Off algorithm shall switch the ramp metering system on and off depending on time of day and/or traffic conditions such as speed, flow or occupancy.

The Queue Override algorithm shall reduce the queue of traffic waiting to join the main carriageway to prevent the queue from adversely affecting non-motorway roads.

The Queue Management algorithm shall control the queue length to acceptable limits to maximise the period of effective ramp metering operation whilst minimising the operation of the queue override function.

The Ramp Metering algorithms shall determine the optimum traffic flow from the ramp to control the flow of traffic on the main carriageway.

The Data Filtering and Fault Management algorithms shall provide meaningful data for use by the various algorithms detailed above.

All algorithms shall use the same units and be able to use inputs, outputs, parameters and variables from other algorithms as required.

All variables and parameters shall be able to be modified or reset remotely whilst the system remains operational, without adversely affecting the system operation during the modification process.

All algorithms shall be switch-able between On, Off and Inhibited. When an algorithm is “Inhibited” it shall continue to run for evaluation purposes, but its output shall be prevented from affecting the actual traffic flow on the ramp.

All default values for parameters shall be changeable. Default values for all parameters and variables shall be retained during periods of power loss and returned to the latest value on power up.

This document defines the processing required to implement these seven groups of algorithms.

6.2 RELEASE ALGORITHM

The Release Algorithm shall set the traffic signals appropriately to provide the required traffic flow released from the ramp. As a secondary function the Release Algorithm shall also monitor the presence of queuing traffic prior to the stop line and monitor the actual release rate.

The Release Algorithm shall have ten different sets of manual signal times, providing ten distinct Release Levels of traffic flow released from the stop line onto the main carriageway.

The Release Algorithm shall also switch the signals off when not in use and manage the transition from off to on and vice versa, via a steady green state of a minimum duration.

The Release Algorithm shall set the traffic signals to the most appropriate Release Level / steady green or off depending on the Release Rate required by the other Ramp Metering algorithms as detailed below.

The Release Algorithm shall ensure that the sequencing of the traffic signals complies with the Traffic Signals Regulations and General Directions 2002 for the operation of traffic signals and that any changes in signal timings are performed safely and within the prescribed sequence.

The Release algorithm shall ensure that the correct sequence of the traffic signals is maintained throughout changes from “Off” to “On” and vice versa, and through all switches between different release levels and throughout the operation of all release levels.
The Release Algorithm shall provide 10 distinct levels of traffic flow / release rate from the ramp onto the main carriageway. Level 10 shall provide the highest traffic flow from the ramp onto the main carriageway (up to the maximum permitted ramp flow \((r_{10} = r_{\text{max}}})\). Level 1 shall provide the lowest traffic flow from the ramp onto the main carriageway (down to the minimum permitted ramp flow \((r_1 = r_{\text{min}}})\).

The signal timings shall be determined so as to minimise the number of vehicles per platoon, whilst maintaining stated maximum and minimum signal times.

The Release Algorithm shall monitor the release loops and record the average number of vehicles leaving per green aspect for each release level when set and the average release flow for each release level when set. This shall provide valuable information for the monitoring of the Release Algorithm performance and assist in the manual calibration of the signal aspect timings for each release level.

The Release Algorithm shall not be synchronised with other algorithms and shall constantly monitor the required release flow from the Arbitration Algorithm in real time and set the required release level accordingly.

The release level \((r_1 \text{ to } r_{10})\) set by the Release Algorithm shall be the release level closest to the required traffic flow \((r)\) from the Arbitration Algorithm as follows:

\[
\text{Set Release Level 1 (} r_1 \text{) if } \quad r < \frac{r_1 + r_2}{2} \\
\text{Set Release Level 2 (} r_2 \text{) if } \quad r_1 + r_2 < r < \frac{r_2 + r_3}{2} \\
\text{Set Release Level 3 (} r_3 \text{) if } \quad \frac{r_2 + r_3}{2} < r < \frac{r_3 + r_4}{2} \\
\text{etc.} \\
\text{Set Release Level 10 (} r_{10} \text{) if } \quad \frac{r_9 + r_{10}}{2} < r < \frac{r_{10} + r_{11}}{2}
\]

The Release Algorithm shall change the desired release level at the time demanded by the change in required release rate and not at the end of any signal time or sequence. (Note: If the desired display time for a signal aspect changes during the display of that aspect, the system shall display the aspect for the new desired signal time (from the original setting of that aspect, not from the change in desired signal time) and not the previously desired signal time.)
The Release Algorithm shall maintain a steady indefinite green signal when the required release rate is closest to the free flow release level as follows:

\[
\frac{r_{10} + r_{ff}}{2} < r < \frac{r_{ff} + r_{off}}{2}
\]

The Release Algorithm shall switch all signals off when the required release rate is closest to the off release level as follows:

\[
\frac{r_{ff} + r_{off}}{2} < r
\]

When the required release rate falls sufficiently to switch the signals on the transition from off to on the Release Algorithm shall set and maintain a steady green signal for at least the minimum green time to ensure that the transition from off is always via a green signal. This is to minimise the potential for vehicle collisions at the stop line by ensuring that an amber signal is always displayed before a red signal.

When the required release rate rises sufficiently to switch the signals off the Release Algorithm shall ensure that the transition from on to off is only performed from a green signal aspect of at least the minimum green time.

The operation of the signals shall be such that when the Ramp Metering system is switched off all traffic signals shall be off.

The inputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>The required release (from arbitration algorithm)</td>
<td>VPH</td>
<td>(r_{min})</td>
<td>(r_{off})</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>(q_{qr}(k))</td>
<td>Measured flow from queue release loops aggregated over the ramp data filtering aggregation period.</td>
<td>VPH</td>
<td>0</td>
<td>6000</td>
<td>1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 1 – Release Algorithm Inputs

The outputs from this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green signal</td>
<td>State</td>
<td>Off</td>
<td>On</td>
<td>N/A</td>
<td></td>
<td>On</td>
</tr>
<tr>
<td>Amber Signal</td>
<td>(Stopping Amber) (time for the signal phases to change from green to red).</td>
<td>State</td>
<td>Off</td>
<td>On</td>
<td>N/A</td>
<td>Off</td>
</tr>
<tr>
<td>Red Signal</td>
<td>State</td>
<td>Off</td>
<td>On</td>
<td>N/A</td>
<td></td>
<td>Off</td>
</tr>
<tr>
<td>Red and Amber Signal</td>
<td>(Starting Amber) (time for the signal phases to change from red to green).</td>
<td>State</td>
<td>Off</td>
<td>On</td>
<td>N/A</td>
<td>Off</td>
</tr>
<tr>
<td>(q_{qr-1} - q_{qr-off})</td>
<td>Record of actual Release Rates for each release level 1 – 10 and free flow and off, to aid manual calibration of signal timings.</td>
<td>VPH</td>
<td>0</td>
<td>4000</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>(vpg_{-1} - vpg_{10})</td>
<td>Record of average number of vehicles released per green signal for each release level 1 – 10 to aid manual calibration of signal timings.</td>
<td>Vcls per green</td>
<td>0</td>
<td>20</td>
<td>0.01</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 2 – Release Algorithm Outputs
The parameters used within this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$gt_{(1-10)}$</td>
<td>Ten green signal times (release levels 1-10);</td>
<td>Seconds</td>
<td>$gt_{(min)}$</td>
<td>$gt_{(max)}$</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>$spa_{(1-10)}$</td>
<td>Ten stopping amber signal times (release levels 1-10);</td>
<td>Seconds</td>
<td>$spa_{(min)}$</td>
<td>$spa_{(max)}$</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>$rt_{(1-10)}$</td>
<td>Ten red signal times (release levels 1-10);</td>
<td>Seconds</td>
<td>$rt_{(min)}$</td>
<td>$rt_{(max)}$</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>$sta_{(1-10)}$</td>
<td>Ten starting amber signal times (release levels 1-10);</td>
<td>Seconds</td>
<td>$sta_{(min)}$</td>
<td>$sta_{(max)}$</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>$gt_{(min)}$</td>
<td>Minimum green time</td>
<td>Seconds</td>
<td>1</td>
<td>30</td>
<td>0.01</td>
<td>2</td>
</tr>
<tr>
<td>$gt_{(max)}$</td>
<td>Maximum green time (Note: this does not apply to the free flow / steady green operational state)</td>
<td>Seconds</td>
<td>1</td>
<td>120</td>
<td>0.01</td>
<td>60</td>
</tr>
<tr>
<td>$spa_{(min)}$</td>
<td>Minimum stopping / (leaving) amber time</td>
<td>Seconds</td>
<td>1</td>
<td>5</td>
<td>0.01</td>
<td>3</td>
</tr>
<tr>
<td>$spa_{(max)}$</td>
<td>Maximum stopping amber time</td>
<td>Seconds</td>
<td>1</td>
<td>5</td>
<td>0.01</td>
<td>3</td>
</tr>
<tr>
<td>$rt_{(min)}$</td>
<td>Minimum red time</td>
<td>Seconds</td>
<td>1</td>
<td>120</td>
<td>0.01</td>
<td>2</td>
</tr>
<tr>
<td>$rt_{(max)}$</td>
<td>Maximum red time</td>
<td>Seconds</td>
<td>1</td>
<td>120</td>
<td>0.01</td>
<td>60</td>
</tr>
<tr>
<td>$sta_{(min)}$</td>
<td>Minimum starting amber (red and amber) time</td>
<td>Seconds</td>
<td>1</td>
<td>5</td>
<td>0.01</td>
<td>2</td>
</tr>
<tr>
<td>$sta_{(max)}$</td>
<td>Maximum starting amber (red and amber) time</td>
<td>Seconds</td>
<td>1</td>
<td>5</td>
<td>0.01</td>
<td>2</td>
</tr>
<tr>
<td>$r_{(min)}$</td>
<td>The minimum practical metered traffic flow that can be achieved with full signal sequences</td>
<td>VPH</td>
<td>0</td>
<td>4000</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>$r_{(max)}$</td>
<td>The maximum practical metered traffic flow that can be achieved with full signal sequences</td>
<td>VPH</td>
<td>0</td>
<td>4000</td>
<td>1</td>
<td>2400</td>
</tr>
<tr>
<td>$r_{(off)}$</td>
<td>The practical free flow traffic flow when only the green aspect is displayed</td>
<td>VPH</td>
<td>0</td>
<td>5000</td>
<td>1</td>
<td>2700</td>
</tr>
<tr>
<td>$r_{(off)}$</td>
<td>The maximum theoretical traffic flow of the ramp with no ramp metering signals</td>
<td>VPH</td>
<td>0</td>
<td>6000</td>
<td>1</td>
<td>3000</td>
</tr>
<tr>
<td>$r_{(lev1)}$</td>
<td>Release level 1 traffic flow</td>
<td>VPH</td>
<td>$r_{(min)}$</td>
<td>$r_{(lev2)}$</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>$r_{(lev2)}$</td>
<td>Release level 2 traffic flow</td>
<td>VPH</td>
<td>$r_{(lev1)}$</td>
<td>$r_{(lev3)}$</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>$r_{(lev3)}$</td>
<td>Release level 3 traffic flow</td>
<td>VPH</td>
<td>$r_{(lev2)}$</td>
<td>$r_{(lev4)}$</td>
<td>1</td>
<td>700</td>
</tr>
<tr>
<td>$r_{(lev4)}$</td>
<td>Release level 4 traffic flow</td>
<td>VPH</td>
<td>$r_{(lev3)}$</td>
<td>$r_{(lev5)}$</td>
<td>1</td>
<td>900</td>
</tr>
<tr>
<td>$r_{(lev5)}$</td>
<td>Release level 5 traffic flow</td>
<td>VPH</td>
<td>$r_{(lev4)}$</td>
<td>$r_{(lev5)}$</td>
<td>1</td>
<td>1100</td>
</tr>
<tr>
<td>$r_{(lev6)}$</td>
<td>Release level 6 traffic flow</td>
<td>VPH</td>
<td>$r_{(lev5)}$</td>
<td>$r_{(lev6)}$</td>
<td>1</td>
<td>1300</td>
</tr>
<tr>
<td>$r_{(lev7)}$</td>
<td>Release level 7 traffic flow</td>
<td>VPH</td>
<td>$r_{(lev6)}$</td>
<td>$r_{(lev7)}$</td>
<td>1</td>
<td>1500</td>
</tr>
<tr>
<td>$r_{(lev8)}$</td>
<td>Release level 8 traffic flow</td>
<td>VPH</td>
<td>$r_{(lev7)}$</td>
<td>$r_{(lev8)}$</td>
<td>1</td>
<td>1700</td>
</tr>
<tr>
<td>$r_{(lev9)}$</td>
<td>Release level 9 traffic flow</td>
<td>VPH</td>
<td>$r_{(lev8)}$</td>
<td>$r_{(lev9)}$</td>
<td>1</td>
<td>1900</td>
</tr>
<tr>
<td>$r_{(lev10)}$</td>
<td>Release level 10 traffic flow</td>
<td>VPH</td>
<td>$r_{(lev9)}$</td>
<td>$r_{(lev10)}$</td>
<td>1</td>
<td>2100</td>
</tr>
</tbody>
</table>

Table 3 – Release Algorithm Parameters
6.3 Arbitration Algorithm

The Arbitration Algorithm shall monitor the required ramp flow rate from the Ramp Metering, Queue Management, Queue Override, and On-Off Algorithms and determine the correct ramp release flow to pass onto the Release Algorithm.

The Ramp Metering, Queue Management, Queue Override, and On/Off Algorithms all provide their desired release rate as outputs to the Arbitration Algorithm. Each of these outputs are recalculated at different times and as such the Arbitration Algorithm shall constantly monitor all of the desired flow rates and recalculate the correct release flow output to the Release Algorithm in real time.

The operation of the ramp metering function is a balance between the desire to prevent flow breakdown on the main carriageway and to prevent excessive delays and congestion on the ramp and adjacent local road network. As each of the different Algorithms concentrates on just one aspect of the whole traffic problem the Arbitration Algorithm must determine which Algorithm has to take priority.

The nature of the traffic problem is such that when the traffic levels are low, the ramp metering algorithm should require a high ramp flow as there is no congestion problem and the queue management algorithms should require a low value to increase the length of the queue. Therefore the highest value will allow the main carriageway to operate normally whilst minimising delays on the slip road. Conversely when the traffic levels are high, the ramp metering algorithm should require a low ramp flow to prevent congestion on the main carriageway but the queue management algorithms may require higher flows to prevent excessive queue delays and lengths.

Therefore the Arbitration Algorithm shall always chose the highest desired release flow from each of the different algorithms providing inputs into the Arbitration Algorithm. Conversely each of these algorithms must provide outputs of the same type and magnitude for the system to operate correctly. Each of these Algorithms outputs shall be calibrated in Vehicles per Hour and be in the range as detailed below.

\[
r = \max\{r_{rm}, r_{qm}, r_{qo}, r_{oo}\}
\]

The inputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>(r_{rm}(k))</td>
<td>The release flow (for the current iteration of the ramp metering algorithm) required by the Ramp Metering Algorithm</td>
<td>VPH</td>
<td>(r_{\text{min}})</td>
<td>(r_{\text{max}})</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>(r_{qm}(k))</td>
<td>The release flow (for the current iteration of the queue management algorithm) required by the Queue Management Algorithm</td>
<td>VPH</td>
<td>(r_{\text{min}})</td>
<td>(r_{\text{max}})</td>
<td>1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The Arbitration Algorithm shall not be synchronised with other algorithms and shall constantly monitor the desired release flows from the other Algorithms and pass on the current desired value to the Release Algorithm in real time.

The required release rate shall be the highest release rate required by the Ramp Metering, Queue Management, Queue Override, and On/Off Algorithms as follows:

\[
r = \max\{r_{rm}, r_{qm}, r_{qo}, r_{oo}\}
\]

The inputs to this algorithm shall be as detailed in the following table:
The outputs from this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_{ov}(k)$</td>
<td>The release flow (for the current iteration of the queue override algorithm) required by the Queue Override Algorithm</td>
<td>VPH</td>
<td>$r_{(min)}$</td>
<td>$r_{(ff)}$</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>$r_{ro}(k)$</td>
<td>The release flow (for the current iteration of the ramp metering algorithm) required by the Switch On-Off Algorithm</td>
<td>VPH</td>
<td>$r_{(min)}$</td>
<td>$r_{(off)}$</td>
<td>1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Table 4 – Arbitration Algorithm Inputs**

6.4 **SWITCH ON-OFF ALGORITHM**

The Switch On-Off Algorithm shall switch the ramp metering system on or off.

The single output from the Switch On-Off Algorithm shall be calibrated in Vehicles per Hour and shall force the Release Algorithm to switch off by setting its desired release level to the highest value flow rate ($r_{ro} = r_{off}$).

Conversely the On-Off Algorithm shall switch the system on by reducing its desired flow rate until the desired flow rate drops below the outputs from the other algorithms.

The lowest output value from the Switch On-Off Algorithm shall be the minimum ramp flow ($r_{ro} = r_{min}$), allowing all of the other desired release Algorithms to control normally.

The Switch On-Off Algorithm shall provide a phased switch off by increasing the output from the minimum to maximum value at a predetermined rate.

The Switch On-Off Algorithm shall have a Manual Override and Time switch to prevent the system from being switched on outside preset times or when the system is manually switched off. The Manual Override and Time switch shall allow the system to operate during four different predefined time periods for each day of the week or when the system is manually switched on.

The Switch On-Off Algorithm shall monitor the traffic conditions to allow the system to switch on when minimum operational levels of Occupancy OR Flow and Occupancy are exceeded during the period of operation.

The Switch On-Off Algorithm shall monitor the main carriageway speed and initiate the switch off sequence or delay switch on if the main carriageway speed is at or above a predetermined maximum operational speed.

The Switch On-Off Algorithm shall monitor the queue presence loop occupancy and hold the switch off sequence at the maximum release rate ($r_{max}$) until the queue at the stop line has dissipated, when the switch off sequence will be allowed to continue.
The Switch On-Off Algorithm shall operate within distinct time periods \((k_{oo})\) every \((t_{oo})\) seconds. At each iteration the output \((r_{oo}(k_{oo}))\) shall be recalculated as detailed below.

Upon each iteration of the Switch On-Off algorithm the desired release flow \((r_{oo}(k_{oo}))\) shall either be maintained at the same value as the previous iteration \((r_{oo}(k_{oo}-1))\) or adjusted by predetermined constant values \((K_{off})\) or \((K_{on})\) as follows:

\[
\begin{align*}
\begin{cases}
  r_{oo}(k_{oo}) = r_{oo}(k_{oo} - 1) & \text{if steady state} \\
  r_{oo}(k_{oo}) = r_{oo}(k_{oo} - 1) + K_{off} & \text{if switching off} \\
  r_{oo}(k_{oo}) = r_{oo}(k_{oo} - 1) - K_{on} & \text{if switching on}
\end{cases}
\end{align*}
\]

When the Switch On-Off Algorithm is in the steady state the desired output \((r_{oo}(k_{oo}))\) shall be maintained on every iteration until the Algorithm state changes to either the “switch on” or “switch off” state.

When the Switch On-Off Algorithm is in the “switching off” state the desired output \((r_{oo}(k_{oo}))\) shall be increased on every iteration by a predetermined amount \((K_{off})\) until the desired output \((r_{oo}(k_{oo}))\) becomes greater than the maximum theoretical free flow \((r_{off})\), when the Algorithm shall change to its steady “off” state.

The Switch On-Off algorithm shall monitor the occupancy of the queue presence loops \((O_{qp1} - O_{qp2})\) during the switching off state and prevent the desired release value from rising above the maximum metered flow rate \((r_{max})\) if the occupancy of either queue presence loop is above the queue presence threshold \((O_{qpt})\). This shall ensure that the system does not go into free flow (i.e. display a steady green signal) until the queue has dispersed.

When the Switch On-Off Algorithm is in the “switching on” state the desired output \((r_{oo}(k_{oo}))\) shall be decreased on every iteration by a predetermined amount \((K_{on})\) until the desired output \((r_{oo}(k_{oo}))\) becomes equal to the minimum release flow \((r_{min})\), when the Algorithm shall change to a steady “on” state.

The Switch On-Off algorithm shall monitor the speed (velocity) of the traffic entering the junction in lane 1 \((v_{in})\) and change into the “switching off” state when the speed reaches the maximum permitted operational speed \((v_{max})\).

The Switch On-Off algorithm shall monitor the speed (velocity) of the traffic into the junction \((v_{in})\) and prevent changing into the “switching on” state unless the speed is below the maximum permitted operational speed \((v_{max})\).

The Switch On-Off Algorithm shall have manual overrides to switch the system operation to “On” or “Off” or to “Timed”, “Timed Occupancy” or “Timed Flow and Occupancy”.

When the system operation is switched to “Timed” the Switch On-Off algorithm shall monitor the day and time of day and change to the “switching on” state when the time of day reaches a switch on time \((T_{on\,(day\,1-4)})\).

When the system operation is switched to “Timed” the Switch On-Off algorithm shall monitor the day and time of day and change to the “switching off” state when the time of day reaches a switch off time \((T_{off\,(day\,1-4)})\).

When the system operation is switched to “Timed Occupancy” the Switch On-Off algorithm shall monitor the day and time of day and the occupancy of the traffic leaving the junction \((O_{out})\) and change to the “switching on” state when the time of day is between a switch on time \((T_{on\,(day\,1-4)})\) and the corresponding switch off time \((T_{off\,(day\,1-4)})\) AND the occupancy exceeds the minimum operational occupancy value \((O_{min})\).
When the system operation is switched to “Timed Occupancy” the Switch On-Off algorithm shall monitor the day and time of day and the occupancy of the traffic leaving the junction ($O_{out}$) and change to the “switching off” state when the occupancy falls below the minimum operational occupancy value ($O_{min}$) OR when the time of day reaches a switch off time ($T_{off(day 1-4)}$).

When the system operation is switched to “Timed Flow and Occupancy” the Switch On-Off algorithm shall monitor the day and time of day, the flow and occupancy of the traffic leaving the junction ($Q_{out}$ and $O_{out}$) and change to the “switching on” state when the time of day is between a switch on time ($T_{on(day 1-4)}$) and the corresponding switch off time ($T_{off(day 1-4)}$) AND either the flow OR the occupancy exceed the minimum operational flow or occupancy values ($Q_{min}$ and $O_{min}$).

When the system operation is switched to “Timed Flow and Occupancy” the Switch On-Off algorithm shall monitor the day and time of day, the flow and occupancy of the traffic leaving the junction ($Q_{out}$ and $O_{out}$) and change to the “switching off” state when both the flow AND occupancy fall below the minimum operational flow and occupancy values ($Q_{min}$ and $O_{min}$) OR when the time of day reaches a switch off time ($T_{off(day 1-4)}$).

The inputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{in(koo)}$</td>
<td>Speed of lane 1 of main carriageway, upstream of the merge area aggregated over the switch on off aggregation period.</td>
<td>kph</td>
<td>0</td>
<td>250</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>$O_{out(koo)}$</td>
<td>Occupancy of main carriageway at the critical position downstream of the merge area aggregated over the switch on off aggregation period.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>N/A</td>
</tr>
<tr>
<td>$Q_{out(koo)}$</td>
<td>Flow of main carriageway at the critical position downstream of the merge area aggregated over the switch on off aggregation period.</td>
<td>VPH</td>
<td>0</td>
<td>10000</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>$T$</td>
<td>Present Day and Time</td>
<td>Day:</td>
<td></td>
<td></td>
<td>1 sec</td>
<td>N/A</td>
</tr>
<tr>
<td>$O_{qp1(koo)}$, $O_{qp2(koo)}$</td>
<td>Occupancy of queue presence loops aggregated over the switch on off aggregation period.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>1%</td>
<td>N/A</td>
</tr>
<tr>
<td>Manual Override to switch the operational state as follows: On / Off / Timed / Timed Occupancy / Timed Flow and Occupancy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 – Switch On-Off Algorithm Inputs

The outputs from this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_{out(koo)}$</td>
<td>Desired Release Rate from the switch On-Off algorithm.</td>
<td>VPH</td>
<td>$r_{min}$</td>
<td>$r_{off}$</td>
<td>1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 7 – Switch On-Off Algorithm Outputs
The parameters used within this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_{\text{on}} )</td>
<td>Time period for each iteration of switch On-Off algorithm.</td>
<td>Seconds</td>
<td>0</td>
<td>120</td>
<td>Multiple of filter algorithm</td>
<td>30</td>
</tr>
<tr>
<td>( r_{\text{min}} )</td>
<td>As defined in Release algorithm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( r_{\text{ff}} )</td>
<td>As defined in Release algorithm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( r_{\text{off}} )</td>
<td>As defined in Release algorithm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( K_{\text{on}} )</td>
<td>Defined step change in release level at each iteration of the on-off algorithm</td>
<td>VPH</td>
<td>100</td>
<td>3000</td>
<td>1</td>
<td>800</td>
</tr>
<tr>
<td>( K_{\text{off}} )</td>
<td>Defined step change in release level at each iteration of the on-off algorithm</td>
<td>VPH</td>
<td>100</td>
<td>3000</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>( v_{\text{max}} )</td>
<td>Maximum operational speed of lane 1 of main carriageway, upstream of merge area.</td>
<td>kph</td>
<td>0</td>
<td>250</td>
<td>1</td>
<td>85</td>
</tr>
<tr>
<td>( O_{\text{min}} )</td>
<td>Minimum operational occupancy of main carriageway, at the critical location downstream of merge area.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>5%</td>
</tr>
<tr>
<td>( Q_{\text{min}} )</td>
<td>Minimum operational flow of main carriageway, at the critical location downstream of merge area.</td>
<td>VPH</td>
<td>0</td>
<td>10000</td>
<td>1</td>
<td>1000</td>
</tr>
<tr>
<td>( O_{\text{age}} )</td>
<td>Occupancy threshold for the queue presence loops to determine the presence of a queue at the stop line.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>35%</td>
</tr>
<tr>
<td>( T_{\text{on(Mon 1)}} ) to ( T_{\text{on(Sun 4)}} )</td>
<td>Times that the Switch On-Off algorithm switches on. Up to four different switch on times per day with different switch on times for different days of the week.</td>
<td>Day: Hour: Min: Sec</td>
<td>00:00:00</td>
<td>23:59:59</td>
<td>1 sec</td>
<td></td>
</tr>
<tr>
<td>( T_{\text{off(Mon 1)}} ) to ( T_{\text{off(Sun 4)}} )</td>
<td>Times that the Switch On-Off algorithm switches off. Up to four different switch off times per day with different switch off times for different days of the week.</td>
<td>Day: Hour: Min: Sec</td>
<td>00:00:00</td>
<td>23:59:59</td>
<td>1 sec</td>
<td></td>
</tr>
<tr>
<td>( \text{Switch On-Off State} )</td>
<td>The state of the algorithm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Switching On / Steady State / Switching Off</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8 – Switch On-Off Algorithm Parameters

6.5 QUEUE OVERRIDE ALGORITHM

The Queue Override algorithm shall reduce the queue of traffic waiting to join the main carriageway to prevent the queue from adversely affecting non-motorway roads.

The queue override algorithm detects the presence of an excessive queue length and reduces the queue length immediately by releasing the traffic from the ramp to generate a sufficient space within the slip road to prevent disruption to the local road network.
The Queue Override shall monitor the queue detection loops in each lane at the maximum permissible queue length and take the measured occupancy for each lane averaged over the queue override trigger period ($t_{qot}$) to give the averaged occupancy for each lane at the maximum queue length ($O_{qo1}(k_{qot})$) and ($O_{qo2}(k_{qot})$) over the aggregation period ($t_{qot}$).

At each iteration of the Queue Override Algorithm, every ($t_{qot}$) seconds the Queue Override Algorithm shall compare the occupancy levels at the maximum queue length ($O_{qo1}(k_{qot})$) and ($O_{qo2}(k_{qot})$) against predetermined Occupancy Thresholds ($O_{qo1t}$) and ($O_{qo2t}$).

If either of the occupancy levels at the maximum queue length ($O_{qo1}(k_{qot})$) and ($O_{qo2}(k_{qot})$) exceed the corresponding predetermined Occupancy Threshold levels ($O_{qo1t}$) and ($O_{qo2t}$) the Queue Override Algorithm shall trigger and set its output ($r_{qo}$) to the ramp flow required to ensure that the queue length is reduced as efficiently as possible ($r_{qomax}$).

Once the Queue Override Algorithm has been triggered, the output shall remain at ($r_{qomax}$) for a time period ($r_{qoc}$) to allow the queue to clear sufficiently.

After the ramp release rate has been set to the queue override maximum value ($r_{qomax}$) for the queue clearance period ($t_{qoc}$) the output shall be returned to the minimum value ($r_{min}$) for a minimum reset time period ($t_{qor}$).

Once the Queue Override Algorithm has triggered and the output has returned to the minimum value ($r_{min}$) the operation of the Algorithm shall be inhibited for time period ($t_{qor}$) before the Queue Override Algorithm is reset and the operation resumes.

$$r_{qo} = \begin{cases} r_{min} & \text{if } O_{qo1} < O_{qo1t} \text{ and } O_{qo2} < O_{qo2t} \\ r_{qomax}(\text{for } t_{qoc}) + r_{min}(\text{for } t_{qor}) & \text{if } O_{qo1} > O_{qo1t} \text{ or } O_{qo2} > O_{qo2t} \end{cases}$$

The inputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_{qo1}(k_{qo})$</td>
<td>Lane 1 Occupancy of slip road at the first detector on the ramp which should</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>be at the maximum permitted queue length, aggregated over the over</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>the queue override trigger time ($k_{qo}$).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_{qo2}(k_{qo})$</td>
<td>Lane 2 Occupancy of slip road at the first detector on the ramp which should</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>be at the maximum permitted queue length, aggregated over the queue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>override trigger time ($k_{qo}$).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9 – Queue Override Algorithm Inputs
The outputs from this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>rqo</td>
<td>Desired Release Rate from the queue override algorithm</td>
<td>VPH</td>
<td>$r_{\text{min}}$</td>
<td>$r_{\text{max}}$</td>
<td>1</td>
<td>$r_{(\text{lev}10)}$</td>
</tr>
</tbody>
</table>

**Table 10 – Queue Override Algorithm Outputs**

The parameters used within this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{\text{qot}}$</td>
<td>Time period for each iteration of Queue Override Algorithm to trigger the queue override operation.</td>
<td>Seconds</td>
<td>0</td>
<td>120</td>
<td>Multiple of filter algorithm</td>
<td>5</td>
</tr>
<tr>
<td>$O_{\text{qo1t}}$</td>
<td>Threshold value for lane 1 occupancy of slip road at the detector on the slip road at the maximum permitted queue length.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>45%</td>
</tr>
<tr>
<td>$O_{\text{qo2t}}$</td>
<td>Threshold value for lane 2 occupancy of slip road at the detector on the slip road at the maximum permitted queue length.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>45%</td>
</tr>
<tr>
<td>$t_{\text{qoc}}$</td>
<td>Time period for operation of maximum queue override desired ramp flow to clear the queue overflow.</td>
<td>Seconds</td>
<td>0</td>
<td>120</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>$t_{\text{qor}}$</td>
<td>Time period required before the Queue Override algorithm is reset following a queue override trigger and operation at the maximum desired queue override ramp flow.</td>
<td>Seconds</td>
<td>0</td>
<td>120</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>$r_{\text{min}}$</td>
<td>As defined in Release algorithm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r_{\text{qomax}}$</td>
<td>The desired flow rate to reduce the queue length to acceptable levels within the required time frame.</td>
<td>VPH</td>
<td>$r_{\text{min}}$</td>
<td>$r_{\text{ff}}$</td>
<td>1</td>
<td>$r_{(\text{lev}10)}$</td>
</tr>
</tbody>
</table>

**Table 11 – Queue Override Algorithm Parameters**

### 6.6 QUEUE MANAGEMENT ALGORITHM

The Queue Management algorithm shall control the queue length to acceptable limits to maximise the period of effective ramp metering operation whilst minimising the operation of the queue override function.

![Figure 5 – Queue Management Algorithm Schematic](ha2006f.doc)
A switch shall be provided to switch between the queue management algorithms defined below and future queue management algorithms.

This switch shall allow the queue management function to be switched off by forcing the desired queue management ramp rate to be the minimum ramp rate \( r_{qm} = r_{min} \).

### 6.6.1 Proportional Occupancy Queue Management Algorithm

The Proportional Occupancy Queue Management Algorithm shall monitor the occupancy at each set of queue detection loops to obtain the average occupancy of the slip road and an estimate of the queue length and set the queue management desired release rate to maintain the queue length at the desired value.

![Proportional Occupancy Queue Management Algorithm](image)

#### Figure 6 – Proportional Occupancy Queue Management Algorithm

The Proportional Occupancy Queue Management Algorithm shall calculate the combined occupancy \( O_{cq} \) from the total number \( n_{poqm} \) of active queue detection loops. Each queue detection loop shall be activated by the setting of a software switch \( L_{q1} - L_{q2} \). The Proportional Occupancy Queue Management Algorithm shall calculate the combined occupancy \( O_{cq} \) for the slip road as follows:

\[
O_{cq} = \frac{\text{SUM} \{ o_{q1} \times L_{q1} ; o_{q2} \times L_{q2} \} } {n_{poqm}}
\]

The Proportional Occupancy Queue Management Algorithm shall compare the combined queue occupancy \( O_{cq} \) against a desired combined occupancy \( O_{descq} \) and adjust the desired ramp release \( r_{poqm} \) by an amount which is proportional to the amount that combined queue occupancy exceeds the desired combined occupancy.

When the combined queue occupancy \( O_{cq} \) is higher than the desired combined occupancy \( O_{descq} \), the Proportional Occupancy Queue Management Algorithm shall increase the desired ramp release \( r_{poqm} \) by an amount proportional to the difference (error) between the combined queue occupancy \( O_{cq} \) and the desired combined occupancy \( O_{descq} \).

\[
r_{poqm} = r_m + K_{poqm} [O_{cq} - O_{descq}]
\]

with \( r_{poqm} \) limited to the range \([ r_{min} \text{ to } r_{max} ]\)

Note: using the formula given above when the combined queue occupancy \( O_{cq} \) is lower than the desired combined occupancy \( O_{descq} \) then the Proportional Occupancy Queue Management Algorithm attempts to reduce the ramp release rate as the desired ramp release rate \( r_{poqm} \) would be less than the ramp metering desired release rate \( r_m \). However as the Arbitration Algorithm always selects the maximum desired release rate between the Ramp Metering and Queue Management Algorithms there is no need to limit the operation the when the combined queue occupancy is greater than the desired combined queue occupancy, although it would not affect the operation if the operation is limited to when the combined queue occupancy is greater than the desired combined queue occupancy.
The inputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_{rm}$</td>
<td>Desired Release Rate from the Ramp Metering algorithm</td>
<td>VPH</td>
<td>$r_{\text{min}}$</td>
<td>$r_{\text{max}}$</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>$O_{q2i}(k_{\text{poqm}})$ to $O_{q2i}(k_{\text{poqm}})$</td>
<td>Occupancy of each slip road queue detector. (Maximum 20 for a 2 lane slip road) aggregated over time period for alternative queue management algorithm.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 12 – Proportional Occupancy Queue Management Algorithm Inputs

The outputs from this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_{\text{poqm}}(k_{\text{poqm}})$</td>
<td>Desired Release Rate from the proportional occupancy queue management algorithm, updated every iteration of the proportional occupancy queue management algorithm.</td>
<td>VPH</td>
<td>$r_{\text{min}}$</td>
<td>$r_{\text{max}}$</td>
<td>1</td>
<td>$r_{\text{rm}}$</td>
</tr>
</tbody>
</table>

Table 13 – Proportional Occupancy Queue Management Algorithm Outputs

The parameters used within this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{\text{poqm}}$</td>
<td>Time period for each iteration of Proportional Occupancy Queue management Algorithm</td>
<td>Seconds</td>
<td>0</td>
<td>120</td>
<td>Multiple of filter algorithm</td>
<td>5</td>
</tr>
<tr>
<td>$K_{\text{poqm}}$</td>
<td>Constant gain factor for Proportional Occupancy Queue Management Algorithm</td>
<td>VPH/%</td>
<td>0</td>
<td>200</td>
<td>0.01</td>
<td>20</td>
</tr>
<tr>
<td>$n_{\text{poqm}}$</td>
<td>Number of queue detection loops used in the Proportional Occupancy Queue Detection algorithm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_{o1} - L_{o2}$</td>
<td>Software switches to enable or disable queue detection loops in the algorithm (Max 20)</td>
<td></td>
<td>0</td>
<td>1</td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>$O_{\text{c}}$</td>
<td>Combined occupancy averaged over all slip road loops</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>N/A</td>
</tr>
<tr>
<td>$O_{\text{deseq}}$</td>
<td>Desired combined occupancy for slip road</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>50%</td>
</tr>
</tbody>
</table>

Table 14 – Proportional Occupancy Queue Management Algorithm Parameters
6.6.2 Weighted Occupancy Queue Management Algorithm

The Weighted Occupancy Queue Management Algorithm adjusts the desired ramp flow required by the ramp metering function by a value depending on the weighted occupancies for each ramp queue detector in each lane.

**Figure 7 – Weighted Occupancy Queue Management Algorithm Schematic**

The Weighted Occupancy Queue Management Algorithm shall operate within distinct time periods (kwoqm) every (twoqm) seconds. At each iteration the output (rwoqm) shall be recalculated as detailed below.

At each iteration the Weighted Occupancy Queue Management Algorithm shall compare the occupancy for each detector (Oqo to Oqn) with occupancy band thresholds for each detector location (Oq1B1 to Oqn2B3).

At each iteration the Weighted Occupancy Queue Management Algorithm shall set the appropriate occupancy level for each occupancy detector (olqo to olqn = 0 to 3).

Set Occupancy Level (olqo to olqn) = 0 if
\[ (Oqo to Oqn) < (Oq1B1 to Oqn2B1) \]

Set Occupancy Level (olqo to olqn) = 1 if
\[ (Oq1B1 to Oqn2B1) < (Oqo to Oqn) < (Oq1B2 to Oqn2B2) \]

Set Occupancy Level (olqo to olqn) = 2 if
\[ (Oq1B2 to Oqn2B2) < (Oqo to Oqn) < (Oq1B3 to Oqn2B3) \]

Set Occupancy Level (olqo to olqn) = 3 if
\[ (Oq1B1 to Oqn2B1) < (Oqo to Oqn) \]

At each iteration the Weighted Occupancy Queue Management Algorithm shall multiply the occupancy level for each occupancy detector by the weighting factor for that occupancy detector (wfqo x olqo to wfqn x olqn) to give a weighted occupancy score for each queue detection location (woqo to woqn).

**woqo = wfqo x olqo**

**woqn = wfqn x olqn**

At each iteration the Weighted Occupancy Queue Management Algorithm shall sum all of the weighted occupancy scores for each lane to obtain a total weighted occupancy (two1 and two2) for each lane.

**two1 = SUM(woqo1 : woqn1)**

**two2 = SUM(woqo2 : woqn2)**

At each iteration the Weighted Occupancy Queue Management Algorithm shall compare the total weighted occupancy for each lane against the total weighted occupancy thresholds for each lane (two1t1 and two2t1) to determine the ramp release adjustment factor for each lane (rwoqmaf1 and rwoqmaf2).

**COMPARE (two1) to Thresholds (two1t1 to two1t1) and SET (rwoqmaf1)**

**COMPARE (two2) to Thresholds (two2t1 to two2t1) and SET (rwoqmaf2)**
At each iteration the Weighted Occupancy Queue Management Algorithm shall compare the ramp release adjustment factor for each lane ($r_{woqmaf1}$ and $r_{woqmaf2}$) and set the final ramp release adjustment factor to be the highest ramp release adjustment factor.

$$r_{woqmaf} = \text{MAX}(r_{woqmaf1}, r_{woqmaf2})$$

At each iteration the Weighted Occupancy Queue Management Algorithm shall set the desired weighted occupancy queue management ramp release rate ($r_{woqm}$) to be equal to the current Ramp Metering desired Ramp Release rate ($r_{rm}$) plus the adjustment factor ($r_{woqmaf}$) as determined by the Weighted Occupancy Queue Management algorithm.

$$r_{woqm} = r_{rm} + r_{woqmaf}$$

The inputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_{rm}$</td>
<td>Desired Release Rate from the Ramp Metering algorithm</td>
<td>VPH</td>
<td>$r_{min}$</td>
<td>$r_{max}$</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>$O_{qo1B1}$ to $O_{qn2B1}$</td>
<td>Occupancy of each slip road queue detector. (Maximum 16 for a 2 lane slip road) aggregated over time period for weighted occupancy queue management algorithm.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>N/A</td>
</tr>
<tr>
<td>$O_{qo1B2}$ to $O_{qn2B2}$</td>
<td>Separate threshold values for occupancy level 2 for each queue detector.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>30%</td>
</tr>
<tr>
<td>$O_{qo1B3}$ to $O_{qn2B3}$</td>
<td>Separate threshold values for occupancy level 3 for each queue detector.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>45%</td>
</tr>
<tr>
<td>$ol_{qo1}$ to $ol_{qn2}$</td>
<td>Occupancy level for each queue detector.</td>
<td>Integers</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>$wf_{qo1}$ to $wf_{qo2}$</td>
<td>Weighting factor for first queue detector on slip road, (also used for queue override function)</td>
<td>Integers</td>
<td>0</td>
<td>1000</td>
<td>1</td>
<td>200</td>
</tr>
</tbody>
</table>

**Table 15 – Weighted Occupancy Queue Management Algorithm Inputs**

The outputs from this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_{woqm}$</td>
<td>Desired Release Rate from the weighted occupancy queue management algorithm, updated every iteration of the weighted occupancy queue management algorithm.</td>
<td>VPH</td>
<td>$r_{min}$</td>
<td>$r_{max}$</td>
<td>1</td>
<td>$r_{rm}$</td>
</tr>
</tbody>
</table>

**Table 16 – Weighted Occupancy Queue Management Algorithm Outputs**

The parameters used within this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$l_{woqm}$</td>
<td>Time period for each iteration of Weighted Average Queue management Algorithm</td>
<td>Seconds</td>
<td>0</td>
<td>120</td>
<td>Multiple of filter algorithm</td>
<td>5</td>
</tr>
<tr>
<td>$O_{qo1B1}$ to $O_{qn2B1}$</td>
<td>Separate threshold values for occupancy level 1 for each queue detector.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>15%</td>
</tr>
<tr>
<td>$O_{qo1B2}$ to $O_{qn2B2}$</td>
<td>Separate threshold values for occupancy level 2 for each queue detector.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>30%</td>
</tr>
<tr>
<td>$O_{qo1B3}$ to $O_{qn2B3}$</td>
<td>Separate threshold values for occupancy level 3 for each queue detector.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>45%</td>
</tr>
<tr>
<td>$ol_{qo1}$ to $ol_{qn2}$</td>
<td>Occupancy level for each queue detector.</td>
<td>Integers</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>$wf_{qo1}$ to $wf_{qo2}$</td>
<td>Weighting factor for first queue detector on slip road, (also used for queue override function)</td>
<td>Integers</td>
<td>0</td>
<td>1000</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>Label</td>
<td>Description</td>
<td>Unit</td>
<td>Min</td>
<td>Max</td>
<td>Resolution</td>
<td>Default</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------</td>
<td>-----</td>
<td>-----</td>
<td>------------</td>
<td>---------</td>
</tr>
<tr>
<td>$wf_{q1}$ to $wf_{q2}$</td>
<td>Weighting factor for next queue detector on slip road</td>
<td>Integers</td>
<td>0</td>
<td>1000</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>$wf_{q3}$ to $wf_{q4}$</td>
<td>Weighting factor for next queue detector on slip road</td>
<td>Integers</td>
<td>0</td>
<td>1000</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>$wf_{q5}$ to $wf_{q6}$</td>
<td>Weighting factor for next queue detector on slip road</td>
<td>Integers</td>
<td>0</td>
<td>1000</td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>$wf_{q7}$ to $wf_{q8}$</td>
<td>Weighting factor for next queue detector on slip road</td>
<td>Integers</td>
<td>0</td>
<td>1000</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>$wf_{q9}$ to $wf_{q10}$</td>
<td>Weighting factor for next queue detector on slip road</td>
<td>Integers</td>
<td>0</td>
<td>1000</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>$wf_{q11}$ to $wf_{q12}$</td>
<td>Weighting factor for next queue detector on slip road</td>
<td>Integers</td>
<td>0</td>
<td>1000</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>$wo_{q1}$ to $wo_{q2}$</td>
<td>Weighted occupancy level factor for each queue detector.</td>
<td>Integers</td>
<td>0</td>
<td>3000</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>$two_{1}$</td>
<td>Total weighted occupancy for lane 1.</td>
<td>Integer</td>
<td>0</td>
<td>24000</td>
<td>1</td>
<td>User defined</td>
</tr>
<tr>
<td>$two_{2}$</td>
<td>Total weighted occupancy for lane 2.</td>
<td>Integer</td>
<td>0</td>
<td>24000</td>
<td>1</td>
<td>User defined</td>
</tr>
<tr>
<td>$two_{11}$ &amp; $two_{21}$</td>
<td>Thresholds for total weighted occupancy level 1, corresponding to adjustment factor 1 for each lane.</td>
<td>Integers</td>
<td>0</td>
<td>24000</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>$two_{12}$ &amp; $two_{22}$</td>
<td>Thresholds for total weighted occupancy level 2, corresponding to adjustment factor 2 for each lane.</td>
<td>Integers</td>
<td>0</td>
<td>24000</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>$two_{13}$ &amp; $two_{23}$</td>
<td>Thresholds for total weighted occupancy level 3, corresponding to adjustment factor 3 for each lane.</td>
<td>Integers</td>
<td>0</td>
<td>24000</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>$two_{14}$ &amp; $two_{24}$</td>
<td>Thresholds for total weighted occupancy level 4, corresponding to adjustment factor 4 for each lane.</td>
<td>Integers</td>
<td>0</td>
<td>24000</td>
<td>1</td>
<td>400</td>
</tr>
<tr>
<td>$two_{15}$ &amp; $two_{25}$</td>
<td>Thresholds for total weighted occupancy level 5, corresponding to adjustment factor 5 for each lane.</td>
<td>Integers</td>
<td>0</td>
<td>24000</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>$two_{16}$ &amp; $two_{26}$</td>
<td>Thresholds for total weighted occupancy level 6, corresponding to adjustment factor 6 for each lane.</td>
<td>Integers</td>
<td>0</td>
<td>24000</td>
<td>1</td>
<td>600</td>
</tr>
<tr>
<td>$two_{17}$ &amp; $two_{27}$</td>
<td>Thresholds for total weighted occupancy level 7, corresponding to adjustment factor 7 for each lane.</td>
<td>Integers</td>
<td>0</td>
<td>24000</td>
<td>1</td>
<td>700</td>
</tr>
<tr>
<td>$two_{18}$ &amp; $two_{28}$</td>
<td>Thresholds for total weighted occupancy level 8, corresponding to adjustment factor 8 for each lane.</td>
<td>Integers</td>
<td>0</td>
<td>24000</td>
<td>1</td>
<td>800</td>
</tr>
<tr>
<td>Label</td>
<td>Description</td>
<td>Unit</td>
<td>Min</td>
<td>Max</td>
<td>Resolution</td>
<td>Default</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------------</td>
<td>---------</td>
</tr>
<tr>
<td>two1t9 &amp;</td>
<td>Thresholds for total weighted occupancy level 9, corresponding to adjustment factor 9 for each lane.</td>
<td>Integers</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>900</td>
</tr>
<tr>
<td>two2t9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>two1t10 &amp;</td>
<td>Thresholds for total weighted occupancy level 10, corresponding to adjustment factor 10 for each lane.</td>
<td>Integers</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>1000</td>
</tr>
<tr>
<td>two2t10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rwoqm1af1 &amp;</td>
<td>Adjustment factors for weighted occupancy level 1 for each lane.</td>
<td>VPH</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>rwoqm2af1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rwoqm1af2 &amp;</td>
<td>Adjustment factors for weighted occupancy level 2 for each lane.</td>
<td>VPH</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>rwoqm2af2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rwoqm1af3 &amp;</td>
<td>Adjustment factors for weighted occupancy level 3 for each lane.</td>
<td>VPH</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>700</td>
</tr>
<tr>
<td>rwoqm2af3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rwoqm1af4 &amp;</td>
<td>Adjustment factors for weighted occupancy level 4 for each lane.</td>
<td>VPH</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>900</td>
</tr>
<tr>
<td>rwoqm2af4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rwoqm1af5 &amp;</td>
<td>Adjustment factors for weighted occupancy level 5 for each lane.</td>
<td>VPH</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>1100</td>
</tr>
<tr>
<td>rwoqm2af5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rwoqm1af6 &amp;</td>
<td>Adjustment factors for weighted occupancy level 6 for each lane.</td>
<td>VPH</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>1300</td>
</tr>
<tr>
<td>rwoqm2af6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rwoqm1af7 &amp;</td>
<td>Adjustment factors for weighted occupancy level 7 for each lane.</td>
<td>VPH</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>1500</td>
</tr>
<tr>
<td>rwoqm2af7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rwoqm1af8 &amp;</td>
<td>Adjustment factors for weighted occupancy level 8 for each lane.</td>
<td>VPH</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>1700</td>
</tr>
<tr>
<td>rwoqm2af8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rwoqm1af9 &amp;</td>
<td>Adjustment factors for weighted occupancy level 9 for each lane.</td>
<td>VPH</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>1900</td>
</tr>
<tr>
<td>rwoqm2af9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rwoqm1af10 &amp;</td>
<td>Adjustment factors for weighted occupancy level 10 for each lane.</td>
<td>VPH</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>2100</td>
</tr>
<tr>
<td>rwoqm2af10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rwoqm1af</td>
<td>Final adjustment factor for weighted occupancy queue management algorithm. Calculated as the maximum adjustment factor for each lane.</td>
<td>VPH</td>
<td>0</td>
<td>2400</td>
<td>1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 17 – Weighted Occupancy Queue Management Algorithm Parameters
6.7 MAIN CARRIAGEWAY METERING ALGORITHMS

The Ramp Metering algorithms shall determine the optimum traffic flow from the ramp to control the flow of traffic on the main carriageway.

A switch shall be provided to switch between the ramp metering algorithms defined below and future ramp metering algorithms.

This ramp metering algorithm switch shall allow the selection of the Demand Capacity and ALINEA outputs depending on the time of day.

6.7.1 Demand Capacity algorithm

The Demand Capacity (DC) control strategy shall regulate the ramp flow to maintain the main carriageway downstream flow at the desired downstream flow. The algorithm shall adjust the ramp flow on each iteration to make up the difference between the measured upstream flow and estimated downstream flow capacity.

The Demand Capacity Algorithm shall calculate the required ramp flow as follows:

\[
r_{dc}(k_{dc}) = \begin{cases} 
q_{des} - q_{in}(k_{dc} - 1) & \text{if } O_{out}(k_{dc} - 1) < O_{cr} \\
r_{min} & \text{else}
\end{cases}
\]

If the measured downstream occupancy \(O_{out}\) is less than the critical occupancy \(O_{cr}\) then the Demand Capacity Algorithm shall calculate the new ramp rate \(r_{dc}(k_{dc})\) by subtracting the measured upstream flow \(q_{in}\) from the desired downstream flow \(q_{des}\) to release the correct number of vehicles from the ramp on to the main carriageway.

If the measured downstream occupancy \(O_{out}\) is greater than the critical occupancy \(O_{cr}\) then the Demand Capacity Algorithm shall set the new ramp rate \(r_{dc}(k_{dc})\) to the minimum permissible ramp flow \(r_{min}\) to prevent flow breakdown on the main carriageway.

Figure 8 – Ramp Metering Algorithm Schematic

Figure 9 - Demand Capacity Algorithm
The inputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_{\text{out}}(k_{dc-1})$</td>
<td>Occupancy of the main carriageway, downstream of the merge at the critical position measured and aggregated over the last (finishing) period $(k_{dc-1})$</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>N/A</td>
</tr>
<tr>
<td>$q_{\text{in}}(k_{dc-1})$</td>
<td>Main carriageway flow into the merge area aggregated over the last (finishing) period $(k_{dc-1})$.</td>
<td>VPH</td>
<td>0</td>
<td>10000</td>
<td>1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 18 – Demand Capacity Algorithm Inputs

The outputs from this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_{dc}(k_{dc})$</td>
<td>Desired Release Rate from the Demand Capacity Algorithm for current iteration of the Demand Capacity Algorithm.</td>
<td>VPH</td>
<td>$r_{\text{min}}$</td>
<td>$q_{\text{des}}$</td>
<td>1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 19 – Demand Capacity Algorithm Outputs

The parameters used within this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{dc}$</td>
<td>Time period for each iteration of Demand Capacity Algorithm</td>
<td>Seconds</td>
<td>0</td>
<td>120</td>
<td>Multiple of filter algorithm</td>
<td>60</td>
</tr>
<tr>
<td>$O_{cr}$</td>
<td>Critical Occupancy at the critical position downstream of the merge point when the maximum traffic flow is maintained and flow breakdown is avoided.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>User defined</td>
</tr>
<tr>
<td>$q_{\text{des}}$</td>
<td>Desired downstream main carriageway flow rate</td>
<td>VPH</td>
<td>0</td>
<td>10000</td>
<td>1</td>
<td>5000</td>
</tr>
<tr>
<td>$r_{\text{min}}$</td>
<td>As defined in Release Algorithm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 20 – Demand Capacity Algorithm Parameters
6.7.2 ALINEA Algorithm

The ALINEA algorithm shall modify the required ramp flow value in proportion to the difference between the measured downstream occupancy and the desired downstream occupancy. If the downstream occupancy is greater than the desired value, ALINEA reduces the ramp flow, whereas if the downstream occupancy is less than the desired value, it increases the ramp flow. Hence, the occupancy subsequently measured downstream is maintained as close as possible to the desired value.

![ALINEA Algorithm Schematic](image)

The ALINEA Algorithm shall calculate the ramp flow \( r_{al} \) as follows:

\[
r_{al}(k_{al}) = r_{al}(k_{al} - 1) + K_{al}[O_{des} - O_{out}(k_{al} - 1)]
\]

with \( r_{al}(k_{al}) \) limited to the range \([r_{min} \text{ to } r_{almax}]\).

The calculated new ramp flow shall be limited to be between the minimum permissible ramp flow and the maximum ALINEA required ramp flow.

The maximum ramp flow that can be required by the ALINEA Algorithm \( r_{almax} \) shall be calculated dynamically and shall be the minimum of either the maximum metered release rate \( r_{max} \) or the actual measured ramp release rate \( q_{qr} \) plus a constant offset value \( \Delta \) as follows:

\[
r_{almax} = \text{MIN}\{r_{max}, q_{qr} + \Delta\}
\]

The ALINEA Algorithm shall calculate the new ramp rate \( r_{al}(k) \) by multiplying the difference between the desired occupancy \( O_{des} \) and the upstream occupancy \( O_{out} \) by a constant gain factor \( K_{al} \); increasing the ramp flow rate if the measured upstream occupancy \( O_{out} \) is less than the desired occupancy \( O_{des} \) and vice versa.

The inputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>( O_{out}(k_{al}-1) )</td>
<td>Occupancy of the main carriageway, at the critical position downstream of the merge as measured on the previous iteration of the ALINEA Algorithm aggregated over the time period for the operation of the ALINEA algorithm</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>N/A</td>
</tr>
</tbody>
</table>
The desired ramp flow calculated by the ALINEA Algorithm on the previous iteration of the ALINEA Algorithm (and truncated to lie within \([r_{\text{min}} - r_{\text{max}}]\)).

Table 21 – ALINEA Algorithm Inputs

The outputs from this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>(r_{\text{al}}(k_{al}))</td>
<td>Desired Release Rate from the ALINEA Algorithm for current iteration of the ALINEA Algorithm.</td>
<td>VPH</td>
<td>(r_{\text{min}})</td>
<td>(r_{\text{max}})</td>
<td>1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 22 – ALINEA Algorithm Outputs

The parameters used within this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>(t_{al})</td>
<td>Time period for each iteration of the ALINEA Algorithm</td>
<td>Seconds</td>
<td>0</td>
<td>120</td>
<td>Multiple of filter algorithm</td>
<td>60</td>
</tr>
<tr>
<td>(O_{des})</td>
<td>Desired Occupancy at the critical position downstream of the merge point.</td>
<td>%</td>
<td>0%</td>
<td>100%</td>
<td>0.1%</td>
<td>(&lt; O_{cr})</td>
</tr>
<tr>
<td>(K_{al})</td>
<td>Constant gain factor for ALINEA Algorithm</td>
<td>VPH/%</td>
<td>0</td>
<td>200</td>
<td>0.01</td>
<td>70</td>
</tr>
<tr>
<td>(\Delta)</td>
<td>Constant ramp flow offset factor.</td>
<td>VPH</td>
<td>200</td>
<td>1000</td>
<td>1</td>
<td>400</td>
</tr>
<tr>
<td>(r_{\text{max}})</td>
<td>As defined in Release algorithm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(r_{\text{min}})</td>
<td>As defined in Release algorithm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 23 – ALINEA Algorithm Parameters

6.8 DATA FILTERING ALGORITHMS

Data filtering algorithms shall calculate smoothed values for flow, speed and occupancy from the raw vehicle data collected by the detectors over the particular and different time periods that they are required for within each algorithm as defined above.

The system shall initially include the following filters:

- Main Carriageway Data Filtering Algorithm to calculate the smoothed flow, speed and occupancy data from the raw vehicle data from the MIDAS (Motorway Incident Detection And Signing) loops.
- Ramp Data Filtering Algorithm to calculate smoothed flow and occupancy as well as number of vehicles passing each loop to be used in the queue estimation and control algorithms.

For both main carriageway and ramp data filtering, if any more sophisticated / accurate algorithms than those specified here are available, they can be proposed by the contractor and will be considered.

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6.8.1 Main carriageway data filtering algorithm

Main Carriageway Data Filtering (MCDF) Algorithm shall calculate the smoothed traffic data, including flow, speed and occupancy on the main carriageway.

The MCDF shall calculate the smoothed values for individual loop pairs (i.e. each lane) as well as for loop sites.

The following terms are used in the subsequent definitions:

**Aggregation period** is the time over which all calculations are carried out.

**Vehicle count** is the number of vehicles detected at the site during the aggregation period.

**Vehicle speed** is the speed of individual vehicle detected by loop detectors (Defined in TR 2177).

**Flow** is the ratio of the vehicle count to the aggregation period.

**Vehicle detection time** is the length of time for which a vehicle is detected at a loop.

**Total detection time** is the sum of the vehicle detection times of the vehicles detected in the lane(s) during the aggregation period.

**Occupancy** is the ratio of the total detection time to the aggregation period, multiplied by 100%.

The vehicle data (vehicle speed and vehicle length) collected by each MIDAS outstation (loop site) shall be used as inputs for the MCDF algorithm.

The MCDF algorithm shall calculate the smoothed flow, speed and occupancy for every loop pair and every site.

In the following calculations, the first three (for \( f, v_{\text{total}} \) and \( t_{\text{total}} \)) shall be calculated every time a vehicle passes a detector, during an aggregation period.

The rest (for \( q_{\text{loop}}, v_{\text{loop}}, o_{\text{loop}}, \tilde{q}_{\text{loop}}, \tilde{v}_{\text{loop}}, \tilde{o}_{\text{loop}} \)) shall be calculated using the total values at the end of each aggregation period as defined by the algorithm using the filter output.

The letter \( m \) is incremented to indicate each new vehicle in the vehicle count calculations. i.e. The first vehicle after the start of each aggregation period has the value \( m=1 \), and the value of the vehicle count after this vehicle has passed is \( f(1) = 1 \), etc.

The letter \( k \) is incremented to indicate each new aggregation period. i.e. The first aggregation period has value \( k=1 \), and the value of the average flow in this aggregation period is \( q_{\text{loop}}(1) \). (NB. This convention is used throughout the report. Different aggregation periods are denoted by the use of different identifiers (e.g. \( k_{\text{all}}, k_{\text{dc}}, \text{etc.} \)).

The need to provide similar data smoothed over different time periods may necessitate that the different algorithm aggregation periods are multiples of the data filtering aggregation period and the relevant algorithms then use values averaged over the particular number of relevant filter time periods.

The smoothed flow, speed and occupancy shall be calculated as follows:

Every time a vehicle passes a detector (loop pair):

The vehicle count \( f(m) \) shall be incremented as follows:

\[
f(m) = f(m-1) + 1
\]

where \( f(m-1) \) is the previous vehicle count.

The speed of this vehicle shall be added to the summated speeds of all previous vehicles to give the new summated speed \( v_{\text{total}}(m) \) as follows:

\[
v_{\text{total}}(m) = v_{\text{total}}(m-1) + v_{\text{veh}}(m)
\]
where \( v_{\text{total}(m-1)} \) is the previous summated vehicle speed.

The total time that the loop has been occupied \( t_{\text{total}(m)} \) shall be increased by the time that this vehicle occupied the loop as follows:

\[
t_{\text{total}}(m) = t_{\text{total}}(m-1) + 3.6 \left( \frac{L_{\text{veh}}(m) + L_{\text{loop}}}{v_{\text{veh}}(m)} \right)
\]

where \( t_{\text{total}(m-1)} \) is the previous total detection time.

At the end of the aggregation period \( T_{\text{agg}} \), the MCDF algorithm shall perform the following calculations for the loop pair and for the entire site:

For each individual loop pair, the mean and smoothed values for flow, speed and occupancy shall be calculated as follows:

The current total values after vehicle \( m \) (the last to pass) shall be used as the totals for the aggregation period:

\[
f(k) = f(m); \quad v_{\text{total}}(k) = v_{\text{total}}(m); \quad t_{\text{total}}(k) = t_{\text{total}}(m)
\]

The mean flow across the loop pair \( q_{\text{loop}}(k) \) shall be calculated as follows:

\[
q_{\text{loop}}(k) = \frac{f(k) \times 3600}{T_{\text{agg}}}
\]

The mean speed across the loop pair \( v_{\text{loop}}(k) \) shall be calculated as follows:

\[
v_{\text{loop}}(k) = \frac{v_{\text{total}}(k)}{f(k)}
\]

The mean occupancy of the loop \( o_{\text{loop}}(k) \) shall be calculated as follows:

\[
o_{\text{loop}}(k) = \left[ \frac{t_{\text{total}}(k) \times 100}{T_{\text{agg}} \times N_{\text{loops}}} \right]
\]

where the number of loops is 1 in this instance (for the individual loop calculation).

The smoothed flow across the loop \( \tilde{q}_{\text{loop}}(k) \) shall be calculated as follows:

\[
\tilde{q}_{\text{loop}}(k) = \tilde{q}_{\text{loop}}(k-1)(1-a_q) + q_{\text{loop}}(k)a_q
\]

where \( \tilde{q}_{\text{loop}}(k-1) \) is the previous smoothed flow.

The smoothed speed across the loop \( \tilde{v}_{\text{loop}}(k) \) shall be calculated as follows:

\[
\tilde{v}_{\text{loop}}(k) = \tilde{v}_{\text{loop}}(k-1)(1-a_v) + v_{\text{loop}}(k)a_v
\]

where \( \tilde{v}_{\text{loop}}(k-1) \) is the previous smoothed speed.

The smoothed occupancy of the loop \( \tilde{o}_{\text{loop}}(k) \) shall be calculated as follows:

\[
\tilde{o}_{\text{loop}}(k) = \tilde{o}_{\text{loop}}(k-1)(1-a_o) + o_{\text{loop}}(k)a_o
\]
where \( \tilde{o}_{loop}(k-1) \) is the previous smoothed occupancy.

For each entire site, the aggregated values \((f, v_{total}, t_{total})\) for all the non faulty loops in the site shall be calculated as detailed below and the above equations shall be used similarly to calculate the smoothed flow, speed and occupancy for the site.

The flow for the site shall be the sum of all the single lane flows taking account of the number of lanes and working loops \(N_{loops}\) at the site and allowing for any faulty loops as detailed in the following section.

\[
\tilde{q}_{site}(k) = \text{sum}\{\tilde{q}_{loop}(k) : q_{loopN}(k)\}
\]

The mean speed for a site shall be the weighted mean of each lane occupancy (weighted by the corresponding single lane flows), taking account of the number of working loops \(N_{loops}\) at the site and allowing for any faulty loops as detailed in the following section.

\[
\tilde{v}_{site}(k) = \frac{\text{sum}\{\tilde{v}_{loop}(k) \times \tilde{q}_{loop}(k) : \tilde{v}_{loopN}(k) \times \tilde{q}_{loopN}(k)\}}{N \times \tilde{q}_{site}(k)}
\]

The mean occupancy of the site shall be the simple arithmetic mean of the single lane occupancies, taking account of the number of working loops \(N_{loops}\) at the site and allowing for any faulty loops as detailed in the following section.

\[
\tilde{o}_{site}(k) = \frac{\text{SUM}\{\tilde{o}_{loop}(k) : o_{loopN}(k)\}}{N}
\]

This provides the smoothed values of flow, speed and occupancy, \(\tilde{q}_{site}(k), \tilde{v}_{site}(k), \tilde{o}_{site}(k)\), for each site.

The inputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>(l_{veh})</td>
<td>Vehicle length</td>
<td>M</td>
<td>0</td>
<td>25.5</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>(v_{veh})</td>
<td>Vehicle speed</td>
<td>Kph</td>
<td>0</td>
<td>255</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Table 24 - Main Carriageway Data Filtering Algorithm Inputs**

The outputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\tilde{q})</td>
<td>Smoothed flow</td>
<td>VPH</td>
<td>0</td>
<td>20000</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>(\tilde{v})</td>
<td>Smoothed speed</td>
<td>Kph</td>
<td>0</td>
<td>200</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>(\tilde{o})</td>
<td>Smoothed occupancy</td>
<td>%</td>
<td>0</td>
<td>100</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

**Table 25 - Main Carriageway Data Filtering Algorithm Outputs**

The constants to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Constant</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T_{agg})</td>
<td>Length of aggregation period</td>
<td>sec</td>
<td>5</td>
<td>30</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>(a_q)</td>
<td>Smoothing factor for flow measurements</td>
<td></td>
<td>0</td>
<td>1</td>
<td>0.01</td>
<td>0.250</td>
</tr>
<tr>
<td>(a_v)</td>
<td>Smoothing factor for speed measurements</td>
<td></td>
<td>0</td>
<td>1</td>
<td>0.01</td>
<td>0.250</td>
</tr>
<tr>
<td>(a_o)</td>
<td>Smoothing factor for occupancy measurements</td>
<td></td>
<td>0</td>
<td>1</td>
<td>0.01</td>
<td>0.250</td>
</tr>
</tbody>
</table>
Table 26 - Main Carriageway Data Filtering Algorithm Constants

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>N_loop</td>
<td>Number of loop pairs at the site</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>site specific</td>
</tr>
<tr>
<td>L_loop</td>
<td>Length of each loop in direction of travel</td>
<td>M</td>
<td>0</td>
<td>6</td>
<td>0.1</td>
<td>2</td>
</tr>
</tbody>
</table>

The variables to this algorithm shall be as detailed in the following table:

Table 27 - Main Carriageway Data Filtering Algorithm Variables

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>f(m)</td>
<td>Vehicle count in aggregation period for each loop pair</td>
<td></td>
<td>0</td>
<td>100</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>vtotal(m)</td>
<td>Summated speed in aggregation period for each loop pair</td>
<td>Kph</td>
<td>0</td>
<td>300</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>ttotal(m)</td>
<td>Summated time occupied in aggregation period for each loop pair</td>
<td>sec</td>
<td>0</td>
<td>300</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>qsite(k)</td>
<td>Flow across the loop site (calculated for each loop site)</td>
<td>VPH</td>
<td>0</td>
<td>20000</td>
<td>0.1</td>
<td>n/a</td>
</tr>
<tr>
<td>vsite(k)</td>
<td>Mean speed across the loop site (calculated for each loop site)</td>
<td>Kph</td>
<td>0</td>
<td>200</td>
<td>0.01</td>
<td>n/a</td>
</tr>
<tr>
<td>osite(k)</td>
<td>Mean occupancy of the loop site (calculated for each loop site)</td>
<td>%</td>
<td>0</td>
<td>100</td>
<td>0.01</td>
<td>n/a</td>
</tr>
<tr>
<td>qloop(k)</td>
<td>Total flow across the loop pair (calculated for each loop pair)</td>
<td>VPH</td>
<td>0</td>
<td>20000</td>
<td>0.1</td>
<td>n/a</td>
</tr>
<tr>
<td>vloop(k)</td>
<td>Mean speed across the loop pair (calculated for each loop pair)</td>
<td>Kph</td>
<td>0</td>
<td>200</td>
<td>0.01</td>
<td>n/a</td>
</tr>
<tr>
<td>oloop(k)</td>
<td>Mean occupancy of the loop pair (calculated for each loop pair)</td>
<td>%</td>
<td>0</td>
<td>100</td>
<td>0.01</td>
<td>n/a</td>
</tr>
<tr>
<td>a_loop (k)</td>
<td>Smoothed flow across the loop pair (calculated for each loop pair)</td>
<td>VPH</td>
<td>0</td>
<td>20000</td>
<td>0.1</td>
<td>n/a</td>
</tr>
<tr>
<td>v_loop (k)</td>
<td>Smoothed speed across the loop pair (calculated for each loop pair)</td>
<td>Kph</td>
<td>0</td>
<td>200</td>
<td>0.01?</td>
<td>n/a</td>
</tr>
<tr>
<td>o_loop (k)</td>
<td>Smoothed occupancy of the loop pair (calculated for each loop pair)</td>
<td>%</td>
<td>0</td>
<td>100</td>
<td>0.01?</td>
<td>n/a</td>
</tr>
<tr>
<td>a_site (k)</td>
<td>Smoothed flow across the site (calculated for each site)</td>
<td>VPH</td>
<td>0</td>
<td>20000</td>
<td>0.1?</td>
<td>n/a</td>
</tr>
<tr>
<td>v_site (k)</td>
<td>Smoothed speed across the site (calculated for each site)</td>
<td>Kph</td>
<td>0</td>
<td>200</td>
<td>0.01?</td>
<td>n/a</td>
</tr>
<tr>
<td>o_site (k)</td>
<td>Smoothed occupancy of the site (calculated for each site)</td>
<td>%</td>
<td>0</td>
<td>100</td>
<td>0.01?</td>
<td>n/a</td>
</tr>
</tbody>
</table>

6.8.2 Main Carriageway Fault Detection Algorithm
The fault signal data from the MIDAS loop pairs is not directly available to the RM system. However, if a single loop in a pair is faulty, its raw vehicle data values for speed and length are all set to the ‘unmeasured’ value - 255. If a single loop is faulty then it is still possible to get valid data for Headway but the RM system does not currently use Headway and therefore this can be ignored.

The ‘unmeasured’ value for speed and length shall be used to infer loop faults as part of the MCDF algorithm as follows:

Every time a vehicle passes a detector (loop pair) the following evaluation shall be made:

\[
\text{IF } v_{\text{veh}}(m) = 255 \text{ AND } l_{\text{veh}}(m) = 25.5 \\
\text{THEN Assume the loop pair is faulty.}
\]

For a three or four lane main carriageway:

If one loop pair out of a number \( n \) of loop pairs for a carriageway of \( n \) lanes at a loop site is faulty, then the following calculation shall be performed at the end of the aggregation period instead of the calculations described previously:

The flow across the faulty loop pair \( q_{\text{loopF}}(k) \) shall be set to be the average of the flows across the non-faulty loop pairs as follows:

\[
q_{\text{loopF}}(k) = \frac{\text{SUM}[q_{\text{loopNF}}(k) : q_{\text{loopNF}(n-1)}(k)]}{(n-1)}
\]

The mean speed across the faulty loop pair \( v_{\text{loopF}}(k) \) shall be set to be the average of the weighted mean speeds across the non-faulty loop pairs as follows:

\[
v_{\text{loopF}}(k) = \frac{\text{SUM}[v_{\text{loopNF}}(k) \times \tilde{q}_{\text{loopNF}}(k) + v_{\text{loopNF}(n-1)}(k) \times \tilde{q}_{\text{loopNF}(n-1)}(k)]}{\text{SUM}[\tilde{q}_{\text{loopNF}}(k) : \tilde{q}_{\text{loopNF}(n-1)}(k)]}
\]

The mean occupancy across the faulty loop pair \( o_{\text{loopF}}(k) \) shall be set to be the average of the mean occupancies across the non-faulty loop pairs as follows:

\[
o_{\text{loopF}}(k) = \frac{\text{SUM}[o_{\text{loopNF}}(k) + o_{\text{loopNF}(n-1)}(k)]}{(n-1)}
\]

These values shall then used for the calculations of smoothed values, \( \tilde{q}_{\text{loop}}(k), \tilde{v}_{\text{loop}}(k), \tilde{o}_{\text{loop}}(k) \) as previously described.

For a two lane main carriageway or if two loop pairs out of three/four at a loop site are faulty or if the MIDAS Outstation is faulty (does not reply to a poll), then the RM function that uses that data shall be inhibited in a controlled manner.

It is desirable that in a later phase a more advance method of handling loop faults/MIDAS Outstation fault is capable of implementation whereby if a particular loop site (MIDAS Outstation) is faulty then an alternative MIDAS station is used as the designated site.

If it is not possible to communicate with any MIDAS Outstation then the RM system shall be switched off in a controlled manner.

6.8.3 Ramp data filtering algorithm

Ramp Data Filtering (RDF) algorithm shall take the individual vehicle data from the traffic monitoring sites (queue, presence and release loops) on the ramp and shall calculate the smoothed traffic data (flow and occupancy).

At the end of the different aggregation periods (e.g. \( k_{\text{seq}}, k_{\text{min}} \) etc.), the smoothed flow and occupancy and vehicle count for every loop shall be calculated from the presence signal.
The presence signal, $p_{Rloop}$, shall be 0 when no vehicle is over the loop and 1 when a vehicle is over the loop. This shall be used to obtain flow and occupancy values from each loop as required. This signal shall be received every $T_{Rloop}$ seconds.

The unsmoothed occupancy, $o_{Rloop}(k)$, during each aggregation period shall be equal to the number of samples for which the presence signal is 1, divided by the total number of samples. (NB. This means that if a queueing vehicle stays over the loop for longer than the aggregation period, then the occupancy during that period will be 100%.

$$o_{Rloop}(k) = \frac{n(p_{Rloop} = 1)}{T_{agg}/T_{Rloop}}$$

where $n$ denotes “number of”.

The vehicle count $f$ for each aggregation period shall be obtained by counting how many times the presence signal drops from 1 to 0.

The unsmoothed flow, $q_{Rloop}(k)$, in each aggregation period shall be obtained by dividing the vehicle count by the length (in hours) of the aggregation period.

$$q_{Rloop}(k) = \frac{3600 f_{Rloop}}{T_{agg}}$$

The smoothed occupancy, $\tilde{o}_{Rloop}(k)$, shall be calculated using

$$\tilde{o}_{Rloop}(k) = \tilde{o}_{Rloop}(k-1)(1 - a_o) + o_{Rloop}(k)a_o$$

The smoothed flow, $\tilde{q}_{Rloop}(k)$, shall be calculated using

$$\tilde{q}_{Rloop}(k) = \tilde{q}_{Rloop}(k-1)(1 - a_q) + q_{Rloop}(k)a_q$$

The inputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_{Rloop}$</td>
<td>Presence signal from each loop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fault signal from each loop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 28 - Ramp Data Filtering Algorithm Inputs

The outputs to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{q}_{Rloop}(k)$</td>
<td>Smoothed flow (veh/hr)</td>
<td>VPH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$o_{Rloop}(k)$</td>
<td>Unsmoothed occupancy (%)</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\tilde{o}_{Rloop}(k)$</td>
<td>Smoothed occupancy (%)</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$f_{Rloop}(k)$</td>
<td>Number of vehicle passing each loop in the aggregation period</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 29 - Ramp Data Filtering Algorithm Outputs

The constants to this algorithm shall be as detailed in the following table:
<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{agg}$</td>
<td>Length of aggregation period</td>
<td>sec</td>
<td>5</td>
<td>30</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>$a_q$</td>
<td>Smoothing factor for flow measurements</td>
<td></td>
<td>0</td>
<td>1</td>
<td>0.001</td>
<td>0.5</td>
</tr>
<tr>
<td>$a_o$</td>
<td>Smoothing factor for occupancy measurements</td>
<td></td>
<td>0</td>
<td>1</td>
<td>0.001</td>
<td>0.5</td>
</tr>
<tr>
<td>$N_{loops}$</td>
<td>Number of loop pairs at the site</td>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of sites</td>
<td></td>
<td>4</td>
<td>10</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>$T_{Rloop}$</td>
<td>Period of loop information</td>
<td></td>
<td>0.01</td>
<td>0.1</td>
<td>0.001</td>
<td></td>
</tr>
</tbody>
</table>

Table 30 - Ramp Data Filtering Algorithm Constants

The variables to this algorithm shall be as detailed in the following table:

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Resolution</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q_{Rloop(k)}$</td>
<td>Unsmoothed flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 31 - Ramp Data Filtering Algorithm Variables

6.8.4 Ramp Fault Detection Algorithm

The RMC shall monitor loop faults from the slip road queue detection, queue presence and queue release (QPR) loops. The ramp QPR loop faults shall be managed in a similar way to that described in the Main Carriageway Fault detection Algorithm as detailed above.

This shall be used to improve the functionality of the queue data filtering algorithm when one or more ramp loops are faulty.

For a two lane slip road:

If one loop out of a number ($n$) of loops for a slip road of is faulty, then the following calculation shall be performed at the end of the aggregation period instead of the calculations described previously:

The flow across the faulty loop $q_{loopF(k)}$ shall be set to be the average of the flows across the non-faulty loop pairs in the same lane ($ln$), as follows:

$$q_{loopF ln}(k) = \frac{SUM[q_{loopNF1 ln}(k) : q_{loopNF(n-1) ln}(k)]}{(n-1)}$$

The mean occupancy across the faulty loop $o_{loopF(k)}$ shall be set to be the average of the mean occupancies across the non-faulty loops as follows:

$$o_{loopF}(k) = \frac{SUM[o_{loopNF1}(k) + o_{loopNF(n-1)}(k)]}{(n-1)}$$

These values shall then used for the calculations of smoothed values, $\tilde{q}_{loop}(k), \tilde{v}_{loop}(k), \tilde{o}_{loop}(k)$ as previously described.

7 SIGNAL HEAD

The signal heads shall use light emitting diodes (LEDs) as the source of light for all aspects and must be capable of being driven by the RMC.

The signal heads shall meet the requirements of TR2206 (Specification for Road Traffic Signals)

The activated aspects on all signal heads shall illuminate and extinguish simultaneously
Each signal aspect shall have a nominal diameter of 200m and visors for each aspect
The lower pair of heads, angled toward the driver, shall be dimmed so as not to dazzle drivers.
The aspects shall be displayed against a non-standard backing board of the dimensions and colour given in Figure 15.
The signal heads shall be designed to be mounted on 110mm diameter poles. Both the main head and the lower head, angled towards the driver, will be mounted on the same pole.

8 AVAILABILITY, RELIABILITY, MAINTAINABILITY REQUIREMENTS
The system shall meet the requirements of Part III of TR 1100.
The signal heads shall meet the relevant parts of TR2206.
The system, when operating together and including all sub-systems and cabling supplied as part of this contract, shall provide an availability of 99.5%. Availability in this context will mean performing fully to this specification and available to perform ramp metering should the conditions so require it.
The system shall have a mean time to repair (MTTR) of no more than 1 hour (excluding travel time to site should that be required).
The system shall have a mean time between failures (MTBF) of at least 1 year.

9 INSTALLATION AND COMMISSIONING REQUIREMENTS
As part of this contract the contractor shall be required to commission the system at each site as the sites and systems become available according to an agreed programme. This shall include:
• Installation of the RMC, loop interface unit, signal heads, any other required equipment and all cabling
• Connection to the mains supply and communications
• Adjustment of the Signal Heads to comply with TR2206
• Bringing the system into operation (commissioning)
• Testing that it is operating correctly on-site (site acceptance testing (SAT)).
• Providing any traffic management (if required).
As part of this, the contractor shall be required to work on live carriageways and must therefore provide, in advance, a method statement showing how the safety of the contractor’s workforce, road users and any others will be safeguarded.
In order to maintain a safe working environment on site, the contractor must adhere to, at the contractors cost, any relevant procedures put in place by the principal contractor and the Highways Agency’s Area Agent.

10 DOCUMENTATION TO BE PRODUCED
Technical documentation shall be produced to meet the requirements of Parts II and III of TR 1100 issue C (or later).
Documentation shall be provided in three paper copies and electronic form using either Microsoft Office and/or Adobe Portable Document Format (PDF).
Within 2 weeks of commencement of the contract and then for the duration of the contract the contractor shall provide a project programme showing key tasks and milestones to achieve completion of the contract. The programme shall be updated at least monthly.
Prior to building the system and in accordance with the contractor’s programme, the contractor shall provide a design specification in order to:
• Give the Highways Agency confidence that the design is progressing according to the programme and according to the functional requirements
• Enable co-ordination of engineering, programme and safety issues with the infrastructure design team and the infrastructure contractor

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The design specification shall contain sufficient detail to fulfil these purposes.

The contractor shall maintain this design specification as an up-to-date definition of the system.

Prior to commissioning the first system the contractor shall provide an operating manual giving all necessary information for a supervisor/user to:

- operate the system
- use all aspects of the supervisory interface
- set up the system to perform ramp metering
- upload data for evaluation
- configure and optimise the performance of the existing algorithms
- back-up and restore data

Within 6 weeks of starting to commission the first system the contractor shall provide a system development manual, giving:

- system designs and diagrams
- commented source code
- flow charts
- system and module descriptions
- configuration information, and

any other information necessary to enable others to evolve the existing algorithms, add new algorithms, add further interfaces and change the functionality of the system.

Within 12 weeks of starting to commission the first system the contractor shall provide a maintenance manual, giving:

- design documentation
- parts lists
- supplier details
- interconnections
- maintenance, diagnostic and trouble shooting information, and

any other information necessary to enable others to maintain the system.

11 TRAINING

Prior to commissioning the first system the contractor shall provide 2 days of operating training for up to 8 people to cover how to:

- operate the system
- use all aspects of the supervisory interface
- set up the system to perform ramp metering
- upload data for evaluation
- configure and optimise the performance of the existing algorithms
- back-up and restore data
Within 6 weeks of starting to commission the first system the contractor shall provide 2 days of system development training for up to 8 people to cover:

- system designs and diagrams
- commented source code
- flow charts
- system and module descriptions
- configuration information, and any other information necessary to enable them to evolve the existing algorithms, add new algorithms, add further interfaces and change the functionality of the system.

At any time following commissioning and during the maintenance period, upon request, the contractor shall provide 2 days of training for up to 8 people to cover:

- design documentation
- parts lists
- contractor details
- interconnections
- maintenance, diagnostic and trouble shooting information, and any other information necessary to enable them to maintain the system (as it was designed by the contractor).

12 CONTRACT MANAGEMENT

12.1 TYPE APPROVAL

The contractor shall support the process of obtaining type approval, where this is required, by providing information about, and explanation of the contractor’s design being put forward.

12.2 CDM

Prior to manufacture of the systems, the contractor shall provide the Planning Supervisor with the following information in order to compile the Pre-tender Health and Safety Plan:

- A Design Risk Assessment (DRA) identifying the risks inherent to the design. This shall include evidence that the risk has been a) eliminated; b) reduced; c) isolated; or c) controlled.

On the completion of installation, the contractor shall provide the Planning Supervisor with the following information in order to complete the Health and Safety File:

- Codes and standards to which the system was designed too;
- As-built drawings; and
- Supplier information.

The contractor shall also ensure that the Operation and Maintenance Manual is made available for viewing by the Planning Supervisor.

12.3 LIAISON REQUIREMENTS

The contractor shall attend monthly meetings to report on and discuss the progress of the contract.

In order to co-ordinate the system supply with the preparation of the infrastructure, and to co-ordinate activities on-site, the contractor shall liaise as required with:

- The Highways Agency and/or its consultants
• The infrastructure designers and contractors
• Regional maintenance contractors
• Area Maintenance Agents
• The Police

13 TEST PHILOSOPHY

The contractor shall provide a means of testing the system by exercising inputs and monitoring outputs, using a test rig. This test rig shall enable and support both bench testing and on-site testing. The contractor shall make this test rig available to the Highways Agency and/or its representatives for factory acceptance testing (FAT) and site acceptance testing (SAT) and support them in using it.

Prior to the delivery of the first system to site and with the use of the test rig, the Highways Agency and/or its representative shall witness testing of the system to ensure it meets the requirements of this specification (factory acceptance testing).

The schedule of factory acceptance tests shall be discussed and agreed with the contractor.

The contractor shall re-submit the system to factory acceptance testing if the design, configuration or software changes.

Upon commissioning of each system on-site and with the use of the test rig, the Highways Agency and/or its representative shall witness testing of the system to ensure it meets the requirements of this specification (site acceptance testing).

The schedule of site acceptance tests shall be discussed and agreed with the contractor.

14 MAINTENANCE

The contractor shall provide maintenance support of a form described below to maintain the specified availability for a period that starts upon commissioning the first system and continues for all systems until 18 months after successful on-site commissioning of the final system. It can be assumed that systems will be deployed on any part of the English motorway network.

Monthly performance payments are paid subject to meeting the service levels described below. The contractor can put forward a method for measuring service levels.

The contractor shall hold a number and selection of spares to enable the specified availability to be achieved.

A primary requirement of the system is the need to be easily enhanced and modified through evolution. Some of this evolution may take place during the maintenance period. In this case the contractor will only be responsible for the maintenance and performance of software, hardware and designs supplied by the contractor.

As part of this, the contractor will be required to work on live carriageways and must therefore provide, in advance, a method statement showing how the safety of the contractor’s workforce, road users and any others will be safeguarded.

In order to maintain a safe working environment on site, the contractor must adhere to any relevant procedures put in place by the Highways Agency’s Area Agent.

14.1 HARDWARE MAINTENANCE

The contractor shall provide on-site service to rectify any fault and restore the system to its state upon completion of successful commissioning within 24 hours of receiving notification of the fault.

The contractor may receive notification of faults by automated alert, e-mail sent by an individual, by telephone or written means.

The contractor shall put in place a means of regularly and remotely monitoring the health of each installed system and shall investigate and resolve any indication that there is a problem. Each installed system shall be checked at least daily.

14.2 SOFTWARE MAINTENANCE

The contractor will provide three types of software support:
• Issue resolution (non-critical)
• Issue resolution (critical)
• Software enhancement

A non-critical software issue is one where the software is preventing the system meeting the performance required in this specification, however it is still possible to operate ramp metering at that site for the benefit of road users.

A critical software issue is one where the software is preventing the system meeting the performance required in this specification in such a way that it is not possible to perform ramp metering at that site.

A software enhancement is a feature or function that is requested or required and that is not currently defined in this specification.

The contractor shall resolve non-critical software issues within one month of notification.

The contractor shall resolve critical software issues within 5 working days of notification.

Resolution of software issues will be defined as tested and working software installed in all the relevant systems.

The contractor shall provide the Highways Agency with an escalation process if there is insufficient progress in the resolution of issues within 75% of the stated response time.

In response to a request for a specified software enhancement, the contractor shall respond within 10 working days with an estimate for the elapsed time and costed time to implement the requirement.
Figure 11 - The Concept of Ramp Metering
Figure 12 - The Ramp Metering Controller and its Interfaces
Figure 13 - Operational Modes of the Ramp Metering Controller (Signal Head Sequences)
Figure 14 - Schematic of Algorithms in the Ramp Metering Controller
Figure 15 - Signal Head Backing Board