1 Purpose

1.1 Guide purpose


1.2 Smart motorway document framework

This guide is part of a suite of smart motorway documents that provide information relating to overall planning, project development, delivery and the on-going operation of smart motorways in New South Wales (NSW). This guideline is included in the group of documents in Table 1.

Table 1: Smart motorway documentation framework

<table>
<thead>
<tr>
<th>Document</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical direction</td>
<td>Core overarching policy defining Roads and Maritime smart motorway implementation intentions.</td>
</tr>
<tr>
<td>Guidelines</td>
<td>A ‘scene setting’ document providing an overview of smart motorways, the elements and a guide for their application in NSW.</td>
</tr>
<tr>
<td>Austroads Guide to Smart Motorways</td>
<td>Provides all road agencies across Australasia with a definite, standardised set of smart motorway information within a single reference document to support the delivery of safe and efficient smart motorways. It primarily comprises guidance on the selection, design and layout of ITS elements within a smart motorway project.</td>
</tr>
<tr>
<td>Roads and Maritime Services Supplement to the Austroads Guide to Smart Motorways</td>
<td>Roads and Maritime supplement issued to clarify, add to, or modify the guidance in the Austroads Guide to Smart Motorways so that it is consistent with NSW practice.</td>
</tr>
<tr>
<td>Design guides</td>
<td>A document set providing further design requirement guidance for the provision, positioning and other traffic engineering considerations of smart motorway elements, to complement the guidance provided in the Austroads Guide to Smart Motorways and supporting Roads and Maritime supplement.</td>
</tr>
<tr>
<td>Specifications</td>
<td>Technical, construction, installation and quality specifications for smart motorway elements including the commissioning (transference to full operational mode) of smart motorway elements.</td>
</tr>
<tr>
<td>Operations</td>
<td>Operating policies and procedures, system and element administration and use documents.</td>
</tr>
</tbody>
</table>

1.3 Guide scope

This design guide provides guidance on vehicle detector placement for smart motorways. It covers design principles, warrants and suggested layouts and spacing for vehicle detectors and associated roadside data processors on or in:
• exit ramps
• entry ramps (unmetered and metered)
• vehicle priority lanes (signalised and non-signalised)
• motorway-to-motorway ramps (unmetered and metered)
• motorway mainline
• motorway-to-motorway abutment
• motorway tunnels
• motorway bridges
• emergency bays.

It does not consider:

• electromagnetic factors, pavement, concrete, road design parameters, communications infrastructure and existing vehicle detection facilities
• stopped vehicle detection
• automatic incident detection requirements for motorway tunnels [13, 14].

The guidance in this document is generic and applicable to any smart motorway. It can be used to assist the development of project drawings, specifications and other guides. It outlines the most common motorway scenarios with examples to assist in further designs.

Note: A definitive detector spacing and positioning specification for a particular project can only be developed once the topology and geometry of a motorway is determined.

1.4 Related material

For guidance on entry ramp metering signal design, operation and warrants, refer to [3] and [4].

The following standard drawings provide typical layouts for priority access lanes. These drawings form part of the Roads and Maritime standard drawings *R1010 Ramp Metering Series* [5]:

• Metered bypass: *R1010-06: Two lanes at stop line (metered bypass) – One at nose*
• Unmetered bypass: *R1010-07: Two lanes at stop line (unmetered bypass) – One at nose*

2 Vehicle detection equipment

In NSW the currently used vehicle detector stations can provide traffic volume, density (occupancy rates), speed, queue length and vehicle classification data on a lane-by-lane basis. This data is essential for the smart motorway functions of intelligence, control and information. Thus, vehicle detection equipment is a mandatory element of any smart motorway.

Collected detection data communicated to the motorway management and control centre serves as the intelligent primary input for:

• motorway performance monitoring and reporting plus predictive performance modelling using historical data
• algorithms that aid automatic incident and congestion detection
• travel-time calculation algorithms and traveller information such as average speeds and motorway conditions
• automatic switch on of Ramp Metering before motorway capacity is reached
• ramp metering algorithms that alter the vehicle release rate for ramp signals
• automatically tuning of speed limit speeds to maintain optimal traffic flow and display on variable speed limit signs.

Detectors placed at regular intervals in each motorway lane, tunnels, all entry and exit ramps and other areas such as emergency bays provide a complete picture of traffic flowing on and off the motorway, plus the extent of any queues, to the control systems and road operators.

Detectors send data to the Roads and Maritime host systems via traffic monitoring units and roadside data processors. While there are numerous vehicle detection technologies available, Roads and Maritime only authorises the use of inductive loop vehicle sensors (ILVS) for the purposes outlined in the Smart Motorway Guidelines. This may change as detector technology improves.

Inductive loop detectors are discussed in Roads and Maritime’s Traffic Signal Design Guide – Section 11 Detectors [7]. A vehicle detection site typically consists of:

• ILVS installed in the road surface
• vehicle detection field processors
• feeder cables from the ILVS to the field processors
• power and communications terminal equipment
• roadside enclosures housing field processor, communications and power supply equipment
• conduits and cabling
• mounting accessories and miscellaneous hardware plus materials for footings, underground cableways and earthworks.

An overview of ITS vehicle detection sites and the detailed installation requirements are given in [6].

Vehicle detectors are used to collect lane occupancy, flow, speed and vehicle length (classification) data. In this document, the following traffic management and traffic control applications are considered:

• ramp metering (RM)
• intersection control (IC)
• traveller information (TI)
• mainline end-of-queue protection (EOQ)
• speed homogenisation (SH)
• automatic incident detection (AID)
• performance monitoring and analysis (PMA)

2.1 Detector position and spacing tolerance

Road designers must consider various conditions when determining loop detector positioning (see [7]):

• pavement resurfacing or reconstruction requirements. A loop wire is vulnerable to damage, but needs to be close to the road surface for optimum sensitivity.
• pavement covering. Loops cannot be installed over any bridge, culvert, stormwater drain or similar structures unless there is at least 80 mm of covering pavement.
• proximity of ferrous metal objects. Loops cannot be installed closer than 300 mm to any ferrous metal object such as a manhole cover or pipe
• maximum distance between loop and the sensor unit is limited to 300 m.

Unless specifically mentioned in this document the tolerance of detector position is the greatest of 5% or 5 m. Where a percentage does not apply (e.g. a detector located next to the ramp’s hard nose) the default tolerance is 5 m.

All detector positions are referenced by the upstream edge of the detector. When a dual loop detector is being discussed, this is the upstream edge of the upstream loop.
Reference is made to detector positions relative to the ramp’s nose (gore) area. Figure 1 and Figure 2 show the location of hard and soft noses for entry and exit ramps.

**Figure 1: Exit ramp - hard and soft noses**

![Exit ramp - hard and soft noses](image)

**Figure 2: Entry ramp - hard and soft noses**

![Entry ramp - hard and soft noses](image)

**Note:** In this document, all detector positions shown are a guide only. They are not prescriptive and depend on a specific site’s characteristics.

**Bridging**

Detectors should be positioned to avoid bridging. This occurs where vehicles are incorrectly detected due to vehicle detector position or type as shown by examples in Figure 3.

**Figure 3: Examples of poor detector positioning**

![Examples of poor detector positioning](image)
2.2 Detector configurations

In this document, four loop detector configurations are used.

**Table 2: Loop detector configurations**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Description</th>
<th>Schematic representation</th>
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<tbody>
<tr>
<td>Single detector</td>
<td>• Single loop</td>
<td>Yellow</td>
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<td>Figure 4</td>
<td>• Single output channel</td>
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<td></td>
<td>• Detection area 2 meters</td>
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<tr>
<td></td>
<td>• Suitable for measuring flow and lane occupancy</td>
<td></td>
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<tr>
<td>SCATS detector</td>
<td>• Single detector</td>
<td>Green</td>
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<tr>
<td>Figure 5</td>
<td>• Single output channel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Detection area 4.5 meters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Suitable for measuring flow and lane occupancy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Additional length is for effective lane occupancy measurements for detecting queues formed by signalised approaches or ramps. The additional length eliminates the risk of zero occupancy during a stationary queue and reduces flow measurement accuracy under dense traffic.</td>
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<tr>
<td>Dual SCATS detector</td>
<td>• Two loops</td>
<td>Red</td>
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<tr>
<td>Figure 6</td>
<td>• Two output channels:</td>
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<tr>
<td></td>
<td>• 1 corresponds to the combined length of both loops</td>
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<tr>
<td></td>
<td>• 2 corresponds to the downstream loop only</td>
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<tr>
<td></td>
<td>• Detection area 4.5 meters</td>
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<tr>
<td></td>
<td>The detector has the same capabilities of SCATS detectors but with increased flow measurement accuracy through a second channel with a shorter loop.</td>
<td></td>
</tr>
<tr>
<td>Dual motorway detector</td>
<td>• Two loops</td>
<td>Blue</td>
</tr>
<tr>
<td>Figure 7</td>
<td>• Two separate detection areas</td>
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<td></td>
<td>• Two output channels</td>
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<tr>
<td></td>
<td>• Detection area 7 meters</td>
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<tr>
<td></td>
<td>• Suitable for multiple applications; measuring flow, lane occupancy, speeds and vehicle length</td>
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</tbody>
</table>
A set of detectors (called a detector station) is often installed across all lanes at the same longitudinal position on a carriageway. A detector station can be a single detector station, a SCATS detector station, a dual SCATS detector station or a dual motorway detector station as a reflection of the individual detectors that compose the station.

Vehicle detectors are used to collect lane occupancy, flow, speed and vehicle length (classification) data. The table provided in Appendix A cross-references vehicle detector station types against the traffic management and traffic control applications for which they are used.

3 Vehicle detectors on motorway ramps

The following section provides design guidance for vehicle detector positioning on smart motorway ramps using graphical examples.

Note: These are guides only. Particular circumstances may require alternative positioning within tolerances. Not all possibilities for configuration are depicted. Further details of ramp metering design principles can be found in [9] and [10].

Figure 8 shows the layout for ramp soft and hard noses.

Figure 8: Example of ramp hard and soft nose
#### 3.1 Exit ramps

Exit ramps have three different types of station positioning, A, B and C. Figure 9 (i) to (viii) depicts suggested exit ramp scenarios illustrating example A, B and C detector positioning.

When the exit ramp leads to a signalised intersection, SCATS detectors (or dual SCATS detectors) are required for queue length detection at two positions:

- **Station A** - placed at the start of the deceleration lane where it has full width.
  - Alternatively this detector can be placed on the mainline next to the start of the deceleration lane (ii, iv).
  - Where there is no deceleration lane, this detector is positioned at the start of the exit ramp (vii).
  - Alternatively for no deceleration lane the detector can be on the mainline, next to the start of the ramp.
  - In multi-lane exit ramps as shown in (vi), an additional A and B station maybe required on both lanes of branch 2 if vehicles are likely to queue on to the motorway rather than upstream along the deceleration lane.

- **Station B** - On the exit ramp, 150 m downstream of where the deceleration lane has full width but not closer than 150 m from the downstream end of the exit ramp e.g. stop line of the signalised intersection. Where there is no deceleration lane, the 150 m is measured from the soft nose of the ramp (vii).

A third dual motorway detector station (C) is required for a number of traffic management and information applications. For ramp metering counting accuracy, flows should be measured at the earliest (furthest upstream) vehicle counting position after the mainline and ramp traffic diverges where ramp traffic is largely in-lane.

The detector station (C) needs to be positioned to minimise bridging (see Section 2.1). The positions of (A) and (B) in Figure 9 are a guide only and may need to be moved if the layout means that lane changing or moving from the ramp to the mainline is a concern. Generally the best position is next to the hard nose of all exit ramp branches.

*Figure 9: Detector positioning - exit ramp*
3.2 Entry ramps

A motorway may have both metered and unmetered entry ramps.

3.2.1 Unmetered entry ramps

A motorway with metered ramps may also have unmetered ramps whose traffic flows need to be considered.

A station D (dual motorway detectors) is required for multiple applications. For ramp metering, flow measurement should occur at the latest vehicle counting position (furthest downstream) before mainline and ramp traffic merges and traffic is mostly in lane.

Generally the best position is next to the hard nose (Figure 10).

*Figure 10: Unmetered entry ramp detector positioning*

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3.2.2 Metered entry ramps

The following sections cover detector positioning and spacing up and down stream of the ramp metering stop line. Scenarios include single and multiple access entry ramps plus vehicle priority lanes.

For the purposes of this design guide, a multiple access entry ramp is one where at least one access lane is longer than 30 m (i.e. the distance from the start of the entry (upstream) to the point where the entries merge). If all access ramps are less than 30 m a single entry ramp treatment is possible allowing for a lower number of detectors to be installed.

### 3.2.2.1 Detector positioning downstream of the ramp metering stop line

Traffic flow should be measured at the latest vehicle counting position before the mainline and ramp traffic merge. A single dual motorway detector station should generally be positioned next to the ramp hard nose as depicted as station G in Figure 11.

*Figure 11: Detector positioning - signalised entry ramp downstream of stop line*
### 3.2.2.2 Priority access

Where there is a strategic need for priority access for vehicles such as freight and high occupancy vehicles (HOV), Roads and Maritime may install priority access facilities on entry ramps. The vehicle priority access lane, also known as a bypass lane, provides a means for vehicles to jump a queue or completely bypass the ramp signals. Design considerations for priority access lanes are noted in the *Roads and Maritime Services Supplement to the Austroads Guide to Smart Motorways* [4] and *Smart Motorway Design Guide for Priority Vehicle Access on Entry Ramps* [10].

Factors that influence the decision to install priority access lanes are discussed in [10].

An example of un-signalised bypass lane detector placement is given in Figure 12.

Station G is the dual motorway detector required for multiple applications. For ramp metering purposes, flow should be measured at the latest vehicle counting position before metered traffic merges with the bypass or mainline therefore a station is required before the end of the physical separation (represented by a thick black line) of the bypass lane as shown in Figure 12 (i).

Note: Figure 12 (ii) depicts a special case where the station is further upstream than the physical separation because it is the latest position with physical separation from the mainline.

*Figure 12: Detector positioning: signalised entry ramp and non-signalised priority access lane downstream of stop line*

Metering of priority access lanes depends on the expected vehicle volumes and the ability of the vehicles to merge safely with the mainline.

The ramp metering examples depicted in Figure 13 shows two signalised entry ramps with physical separation. Flow must be measured (G) at the latest vehicle counting position before the metered traffic of both ramps merges together or with the mainline.

It is recommended that a **dual motorway detector** be placed before the end of the physical separation (thick black line) between both metered ramps.

If no physical separation exists the station must be placed 1.5 m (+/- 0.5 m tolerance) downstream of the stop line.
3.2.2.3 Detector positioning upstream of the ramp metering stop line

This section shows examples for single entry ramp access and multiple access entry ramp (all access ramps less than 30 m).

All stations (E) are composed of dual SCATS detectors which are required for ramp metering queue detection.

Single access entry ramp examples shown in Figure 14 demonstrate the following placement and spacing rules:

1. Place one station at the ramp metering stop line providing a gap of 0.5 m upstream of the stop line (+/- 0.5 m tolerance).
2. Place one station at the start (upstream) of the ramp.
3. Place one station 50 m downstream from the start of the ramp.
4. Place one or more equidistant stations between item in rule 1 and 3 as required. These stations should be no more than 150 m apart.

Note: Additional stations may be added to assist in preventing entry ramp queues blocking entry to the bypass lane. Stations should be located next to the start of the bypass lane and 50 m downstream.
Multiple access entry ramp examples shown in Figure 15 demonstrate the following placement and spacing rules:

1. Place one station at the start (upstream) of every ramp access point.
2. If ramp access is longer than 70 m place an additional station 50 m downstream of the station in rule 1.
3. If the ramp access is longer than 220 m, place one or more equidistant stations between the station in rule 1 and the downstream entries. The additional stations must be no more than 150 m apart.
4. Place one station at the access merge point.
5. Place one station at the ramp metering stop line providing a gap of 0.5 m upstream of the stop line (+/- 0.5 m tolerance).
6. Place one or more equidistant stations between those in rules 4 and 5. These stations must be no more than 150 m apart.
3.3 Metered motorway-to-motorway ramps

Metered motorway to motorway ramps should be positioned using the following guides:

1. Position a SCATS detector (O) for queue detection at the start of the deceleration lane where it has full width. In the absence of a deceleration lane this detector should be positioned at the start of the exit ramp (similar to station A in Figure 9 (vii)).
   Note: Alternatively, position (O) on the mainline next to the start of the deceleration lane (Figure 16 (iii)).

2. A dual SCATS detector station (P) is required for ramp metering queue detection on the exit ramp, 150 m downstream of the spot where the deceleration lane has full-width. In the absence of a deceleration lane, the 150 m is measured from the soft nose of the ramp Figure 9 (vii).

3. Several dual SCATS detector stations (E) are required for ramp metering queue detection:
   a. Place one station at the ramp metering stop line providing a gap of 0.5 m upstream of the stop line (+/-0.5 m tolerance).
   b. Place one or more equidistant stations between station (P) and the station in point 3a. These additional stations must be no more than 150 m apart.

4. Detector positions downstream of the stop line follow the guides in section 3.2.2.
Figure 16: Detector positioning - metered motorway-to-motorway ramp

(i)  
(ii)  
(iii)  

4 Vehicle detectors on the mainline

These positioning and spacing guides can be applied to any similar environment such as a tunnel or motorway to motorway abutment.

Tunnels, bridges and other complex mainline type environments should follow the spacing guides for complex ramp examples i.e. equidistant detectors placed at 150 meters maximum. See [13] and [14].

Road designers must consider the positioning of detector stations relative to the existing infrastructure or geometric features of the mainline (mainline positioning) and then determine the location of remaining stations based on minimum spacing requirements (mainline spacing).

4.1 Mainline positioning

This section includes vehicle detector mainline positioning guidelines relative to various smart motorway interventions and infrastructure.
4.1.1 Relative to exit ramps

1. Position a dual motorway detector (M) upstream of the start of the deceleration lane with the exact position to be determined by the weaving area depicted in Figure 17. If exit ramp flows modify the weaving area, position the detector station at the upstream boundary of the weaving area.

Note: Roads and Maritime requires the weaving area upstream boundary position to be estimated via a site survey during peak hour traffic. Avoiding the survey may cause a real-time application delay in identifying an active bottleneck. This can be addressed by retrofitting another detector station if operational experience demonstrates a need.

2. Position a second dual motorway detector (N) next to (up to 200 m downstream of) the exit ramp hard nose.

Figure 17: Mainline detector positioning relative to exit ramp

4.1.2 Relative to metered entry ramps

There are two cases for mainline detector station positioning near entry ramps; where an entry ramp merge is and is not present.

4.1.2.1 Mainline detector with entry ramp merge

1. Position dual motorway detectors (F) between 500 to 2000 m upstream of the soft nose.
   a. This station can be replaced by the (N) station provided it is within range and there are no entries or exits to the mainline between the station and the metered entry ramp.

2. Position dual motorway detectors (H) between 100 to 300 m upstream of the soft nose.

3. Place dual motorway detectors (J) at the end of the taper.

4. Place dual motorway detectors (I) 20 m downstream of the soft nose for ramp metering.
   a. If the distance between stations I and J is greater than 150 m, intermediate equidistant stations (K) are required for ramp metering. These stations should be no more than 150 m apart.
   b. If the distance between the I and J stations is larger than 600 m, the spacing of K stations can be relaxed to 200 m to compromise on the number of stations required.
4.1.2.2 Mainline detector with no entry ramp merge

With no entry ramp merge, there is less likely to be issues with weaving across lanes.

1. Position dual motorway detectors (F) between 500 to 2000 m upstream of the soft nose.
   a. This station can be replaced by the (N) station provided it is within range and there are no entries or exits to the mainline between the station and the metered entry ramp.

2. Place dual motorway detectors (L) within 10 m upstream of the hard nose for multiple applications. (L) is a compromise of (H) and (I). An alternative may be to have (H), (I), (J) and (K) instead of (L).

3. Place dual motorway detectors (J) 200 m downstream of the soft nose. This is required for multiple applications.

4.1.3 Relative to unmetered entry ramps

Detector stations (M) and (N) are required for multiple applications.

Station (M) is positioned next to the entry ramp hard nose. It may be positioned up to 200 m upstream of the hard nose.

A station (N) is positioned next to the end of the taper (up to 200 m downstream of the end of the taper).

Figure 20 provides an example. Where there is no merge, similar to Figure 19, station (N) should be positioned 200 m downstream of the soft nose.
4.1.4 Relative to lane use management (LUM) gantries

1. Where gantry positioning is decided as part of the same project process of detector positioning, the corresponding loop detector stations can generally be unified with some of the detector stations described in sections relating to exit ramps and metered entry ramps. See also section 9.4.7 of [8].

2. Where detector positioning is not part of a gantry positioning project, dual motorway detectors should be placed 10 m upstream of each LUM gantry. Existing loop installations can be accepted if they are within 10 m downstream or 50 m upstream of the gantry.

4.1.5 Relative to potential bottlenecks

Road designers should also consider mainline sections that may become active bottlenecks under certain levels of traffic demand. Potential localised bottlenecks include:

- lane drops/gains
- shoulder/motorway end
- lane narrowing
- upgrades/downgrades
- tunnel entrances
- emergency refuge areas
- curves
- sun strikes.
4.1.5.1 Detector placement for identified localised bottlenecks

1. Place multiple application dual motorway detectors (M) 50 m upstream of the bottleneck position.
2. Place multiple application dual motorway detectors (N) at the potential bottleneck site.

4.1.5.2 Detector placement for sparse bottleneck (weaving section)

1. Place multiple application dual motorway detectors (M) at the upstream boundary of the weaving section.
2. Place multiple application dual motorway detectors (N) at the potential bottleneck site.
4.2 Mainline Spacing

After the mainline positioning described in Section 4.1 has been completed, additional vehicle detector stations (R) must be added and spaced to comply with the warrants in [2].

Roads and Maritime expects that no carriageway spacing larger than 500 metres exist. A tolerance of 20% is acceptable for an individual station where it needs to be moved or adjusted to fit other purposes such as matching stations side-by-side across multiple carriageways.

5 Vehicle Detectors in Tunnels


Tunnels should be considered complex environments and thus have different spacing requirements. See [13] and [14].

6 Vehicle Detectors in Emergency Bays

Roads and Maritime may consider installing a vehicle detection loop in the emergency bays to immediately alert road operators to its usage. This will be decided at the detailed design stage and detector location will depend on motorway and emergency bay geometry and planned CCTV coverage.
## Appendix A

Vehicle detectors are used to collect lane occupancy, flow, speed and vehicle length (classification) data. The following table cross-references vehicle detector station types against the traffic management and traffic control applications for which they are used.

<table>
<thead>
<tr>
<th></th>
<th>RM</th>
<th>IC</th>
<th>TI</th>
<th>EOQ</th>
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*Table 3 - Dependencies between traffic management and traffic control applications and detector stations*

### Key
- **RM**: Ramp metering
- **IC**: Intersection control
- **TI**: Traveller information
- **EOQ**: Mainline end of queue protection
- **SH**: Speed homogenisation
- **AID**: Automatic incident detection
- **PMA**: Performance monitoring and analysis
## References

The following resources are directly referenced in this document. Some references may have limited access for non-subscribers.

<table>
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<th>Ref #</th>
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