Smart motorway design guide

Tunnel traffic management
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1 Design guide information

1.1 Design guide purpose

The purpose of this design guide is to support Roads and Maritime Services (Roads and Maritime) Smart Motorway Technical Direction[1] and the Smart Motorway Guidelines[2].

1.2 Smart motorway document framework

This design guide is part of a suite of smart (managed) 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 design guide is included in the group of documents highlighted 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>Design guides</td>
<td>A document set providing design requirement guidance for the provision, positioning and other traffic engineering considerations of smart motorway elements.</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>

Note: The design guide group of documents also includes external primary reference documents with a Roads and Maritime supplement to define Roads and Maritime enhanced practice, complementary material or departures. This is an interim measure until a complete suite of design guides are available.

1.3 Design guide scope

This design guide provides guidance relating to managing traffic on smart motorways in and near tunnel environments, including:

- Smart motorway principles for managing traffic on the approaches to, within and downstream of tunnels
- Smart motorway elements supporting tunnel traffic management
- Supplementary research and information.
This design guide does not cover tunnel-specific traffic safety and environmental management systems such as those required for drainage, fire safety, ventilation, air quality, noise, lighting, radio re-broadcast and public address. These are covered in the Austroads Guide to Road Tunnels (AGRT) Part 2: Planning, Design and Commissioning[3], which should be read in conjunction with this design guide.

Short underpasses are out of scope for this design guide.

1.4 Terminology

Roads and Maritime Services has developed the following definitions for tunnels and underpasses:

**Tunnel** means a motor vehicle underpass which has a continuous roof structure equal to or greater than 120m in length, measured parallel to the road alignment.

**Long underpass** means a motor vehicle underpass which has a continuous roof structure equal to or greater than 60m and less than 120m in length, measured parallel to the road alignment.

**Short underpass** means a motor vehicle underpass which has a continuous roof structure less than 60m in length measured parallel to the road alignment.

Note that distances in definitions are continuous unless the roof is open over a length of at least 20 metres.

In reference to the definitions above, this design guide is applicable to smart motorway sections approaching, within and downstream of tunnels and long underpasses. The remainder of this document refers to both tunnels and long underpasses as ‘tunnels’.

1.5 Complementary material

The other smart motorway design guides and supplements provide important design principles and guidance that are still of relevance to tunnel environments. Specific complementary materials for each element discussed in this guide are identified in subsequent sections.

If there are any differences in practice between this Roads and Maritime design guide and other complementary material, this Roads and Maritime design guide will apply.

Note that some smart motorway specifications are still in development and the latest list of approved Roads and Maritime specifications should always be referred to.

1.6 Document structure

The remainder of this design guide is structured as follows:

Section 2 provides an overview of the smart motorway principles for tunnel traffic management.

Section 3 provides design guidance relating to smart motorway elements used for traffic monitoring/surveillance (intelligence) and traveller information functions.
Section 4 provides design guidance relating to smart motorway elements for traffic control functions.

Section 5 provides design guidance relating to tunnel closure management, which requires integrated use of a range of smart motorway elements.

Section 6 provides information regarding other smart motorway design considerations, including emergency stopping bays and safeguarding for retrofitting of smart motorway control elements.

Section 7 provides the appendices including: a glossary, reference list, overview of relevant international research, and background information regarding the spacing requirements for smart motorway ITS devices in tunnels.
2 Smart motorway principles for tunnel traffic management

2.1 Smart motorway principles

Smart motorways are managed through the application of a range of operational services, supported by ITS, in order to achieve the following objectives:\[2\]:

- Improve motorway network efficiency and productivity by optimising traffic throughput and vehicle speeds
- Improve the safety of the road environment for all road users through reduced stop-start conditions, improved incident management and increased road monitoring
- Deliver journey reliability via consistent travel times, travel speeds and road conditions.

As outlined in the Smart Motorway Guidelines\[2\], the key concept of managing any type of network, including motorways and tunnels, is active monitoring and the subsequent control of the users of the network based on available intelligence. A smart motorway therefore applies an integrated set of intelligence, control and information functions to allow operators to manage in real-time the traffic entering, existing and traversing a motorway.

**Intelligence** functions enable continuous monitoring, surveillance and analysis of traffic conditions. They can support control and information functions that automatically implement a response to changing traffic conditions or otherwise alert operators.

**Control** functions use outputs from the intelligence function to proactively manage traffic and improve motorway performance for road users. In particular, smart motorways introduces the metering of entry ramp traffic to optimise mainline traffic flow and prevent or reduce the occurrence of flow breakdown.

**Information** functions disseminate real-time traveller information to assist road users in making informed decisions regarding their journeys and to help operators manage network demand particularly during heavy congestion and incidents.

Motorway tunnels are built to provide additional system capacity and should deliver improved journey outcomes for road users in line with smart motorway objectives above. For each smart motorway element, the key design principles that apply to general motorway environments (as described in the Roads and Maritime series of smart motorway design guides and supplements) also apply to tunnel environments.

2.2 Specific considerations for tunnel environments

While in the past tunnel environments have been managed to a greater level than open motorway environments, this has primarily been driven by safety requirements, and tunnel environments still need to be upgraded to meet smart motorway objectives outlined in Section 2.1.
However, tunnel environments have differing characteristics to open motorway environments (refer to Section 2.2.1), and there are some additional considerations when designing a motorway section including a tunnel environment (refer to Section 2.2.2). The focus of this design guide is to identify how the smart motorway elements should be applied to motorway tunnel environments to ensure that these considerations are addressed whilst maintaining whole-of-network performance and driving consistency.

2.2.1 Tunnel characteristics

Road tunnels are constrained road environments that differ from open-air motorway sections. Tunnel environments have a higher road safety risk and tunnel incidents may be of greater severity both for road users and in terms of impact on the surrounding road network. This leads to greater emphasis on emergency and incident management (refer to Section 2.2.2.1). The high potential impacts of full or partial tunnel closures on the rest of the road network necessitates the use of smart motorway elements across a much wider network than just the immediate tunnel approaches and exits, in order to divert traffic away from the tunnel section so as to maximise road safety and minimise congestion.

Some examples of the physical characteristics of tunnels which impact on the design of traffic management include:

- Limited overhead space in tunnels, which may influence the size of smart motorway devices and requirements for over-height vehicle control
- Restrictions on vertical and horizontal alignment in tunnels, which may result in visual restrictions and require additional systems for management of over-height vehicles and different spacing of smart motorway devices compared to other locations
- Tunnel air quality and ventilation requirements arising from tunnel geometry, which are impacted by management of traffic flows within the tunnel.

However, the implementation of reduced speed limits, the absence of roadside obstacles/distractions and the fact that tunnels are a controlled environment with extensive fire and life safety facilities can also impact on driver perception and awareness and result in improved road safety in tunnel environments.

Some specific considerations when designing a smart motorway section that includes a tunnel are outlined below.

2.2.2 Additional design considerations for tunnel environments

The Additional design considerations for tunnel environments include tunnel emergency and incident management, over-height vehicle management and achieving consistency in driving experience.

2.2.2.1 Emergency and incident management

Smart motorway elements in and near road tunnels should be designed to maximise road safety and minimise the risk of incidents occurring within the tunnel environment. This includes minimising the occurrence of flow breakdown and congestion to reduce the risk of stationary or queuing vehicles within the tunnel.
To ensure effective integration with the operation of other tunnel emergency managements systems, smart motorway elements need to support the requirements of a tunnel’s Concept of Operations and the functions of a tunnel’s operations management and control system (OMCS). Design of smart motorway elements should be driven by operational requirements, including needs of incident responders/emergency services and maintenance crews.

Tunnel emergency/incident management should consider requirements for responses at three levels:

- Local area responses, which address the immediate safety issues on the carriageway in the local area surrounding the incident location.
- Tactical responses, which address the re-routing of traffic around the incident location and reducing speed limits to slow traffic arriving at the incident location.
- Strategic responses, which address the wide area issues of the incident and discourage new traffic from coming into the incident location. Strategic responses require a whole-of-network approach to enable coordinated responses across boundaries between different road operators for the urban motorway and arterial road network.

Installation of smart motorway elements further upstream and downstream of road tunnels will therefore facilitate improved traffic flows and safety within the tunnel section, assist with traffic diversion during incidents and are also required for over-height vehicle management.

If smart motorway elements are not already installed or planned for motorway sections upstream/downstream of a tunnel (on the basis of other smart motorway warrants), then their installation on upstream and downstream motorway sections may still be justified to support tunnel traffic and incident management based on operational requirements (refer to Sections 3 to 5 for further details).

In relation to emergency and incident management, smart motorway elements assist in:

- Rapidly detecting and verifying an incident impacting tunnel operations and then to implement a traffic control treatment (e.g. to close lanes or points of tunnel access)
- Preventing vehicles from entering a tunnel during an emergency
- Minimising the volume of vehicles and time period that vehicles are trapped in a tunnel
- Provide rapid and safe access and staging areas for incident operators and emergency vehicles to further minimise incident response times
- Communicating information to motorists on conditions ahead and required actions (for road users inside and on approach to the tunnel)
- Enabling advance diversion of traffic on the connecting motorway and arterial road network away from the affected motorway section
- Managing conditions downstream of the tunnel to facilitate traffic exiting the tunnel and minimise the risk of any downstream congestion extending back into the tunnel during an incident
• Managing traffic in the opposing carriageway direction if required to enable safe diversion of vehicles using a turn-around facility
• Returning the tunnel road network to normal conditions as soon as possible following an incident, so as to minimise delay for road users
• Preventing over-height vehicles and other vehicles that pose a safety risk to tunnel structures from entering.

Smart motorway elements need to have greater resilience in the event of an emergency such as a fire or flood so that the smart motorway system can continue to operate to improve the safety of people in the tunnel.

2.2.2.2 Over-height vehicle management

Management of over-height vehicles\(^1\) is an important consideration for smart motorways in and near road tunnels. Over-height vehicle collisions with tunnel structures can have significant consequences and impacts for road users, road managers and transport providers in relation to road safety, operational risk, vehicle and infrastructure damage and associated costs. Vehicles may be over-height as a result of driver non-compliance with network access restrictions or due to malfunctioning or unsafe set-up of the vehicle and its load.

Over-height vehicle management systems have been developed that can detect the presence of an over-height vehicle upstream of low-clearance infrastructure, initiate an advance vehicle warning (eg via advisory signing) to drivers and if necessary, tunnel closure control measures to prevent an over-height vehicle from entering a tunnel.

These systems are further discussed in Section 3.7 of this guide. The need for over-height vehicle management should be considered in the development of other smart motorway elements that can also support the management of over-height vehicles on the approaches to road tunnels. This may include other elements detailed in Sections 3 to 6 such as vehicle detectors, CCTV, variable message signs, ramp metering signals, LUMS and VSL and emergency stopping bays.

2.2.2.3 Consistent driving experience

Tunnels have traditionally been equipped with a greater extent of traffic management elements than open motorway environments in order facilitate emergency and incident management as outlined in Section 2.2.2.1.

As NSW motorways, including tunnel environments, are progressively upgraded to smart motorways that proactively optimise traffic flow at all times (and not just manage traffic during incidents), there is a need to ensure that there is consistency in design and application of each smart motorway element that is visible to road users across the network.

Consideration should be given to the look and feel of the smart motorway environment to provide a consistent driving experience when transitioning into, through and out from road tunnels.

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\(^1\) In NSW, a vehicle is defined as over-height if its height exceeds 4.3 metres
This will help to ensure motorists are given clear and unambiguous information throughout the motorway route and reduce driver confusion, which may also help to improve compliance with traffic control treatments.

Specific considerations for individual smart motorway elements are further discussed in Sections 3 to 5.
3 Traffic monitoring/surveillance and traveller information elements

3.1 Overview

Traffic monitoring/surveillance (intelligence) and traveller information elements are considered as foundation ITS for smart motorways, and should be incorporated in the design of all motorway tunnel projects.

This section provides specific guidance for application of the following smart motorway elements to motorway sections with tunnels:

- Vehicle detection (Section 3.2)
- Closed-circuit television (CCTV) (Section 3.3)
- Automatic incident detection (AID) (Section 3.4)
- Emergency telephones (Section 3.5)
- Variable message signs and tunnel message signs (Section 3.6)
- Over-height vehicle management (Section 3.7).

3.2 Vehicle detection

Vehicle detection is required for all smart motorways to collect traffic data to support other real-time intelligence, control and information functions.

Vehicle detection within tunnels and on adjacent motorway sections should generally follow the principles and requirements outlined in the Guidelines for Positioning and Spacing of Loop Detectors for a Level 3 Managed Motorway[4].

The warrants for vehicle detection outlined in the Smart Motorway Guidelines[2] are not applicable to tunnels.

3.2.1 Design principles

Detector layout within the mainline and ramps needs to be consistent with the ramp metering algorithm (primary need) and LUMS/VSL operations for managing mainline traffic.

With regards to ramp metering system requirements, detectors should be placed to help manage potential bottleneck locations within tunnels including at sag vertical curves and upgrades.

Detectors should be provided on exit ramps and upstream of exit ramps to enable detection of queuing from the exit ramps onto the mainline and in the tunnel. If detected, tunnel message signs can then be used to warn motorists in the tunnel of queues ahead (refer to Section 3.6).
Detector layout should also consider requirements for automatic incident detection if an algorithmic approach using detector data is used (refer to Section 3.4). Automatic incident detection in tunnels will require much closer spacing of detectors than is required for other functionalities due to the need to rapidly detect the occurrence of an incident at any location on the tunnel mainline.

### 3.3 Closed circuit television cameras

Closed Circuit Television Cameras (CCTV) systems are required in all tunnels to facilitate the timely identification of incidents, breakdowns and congestion and to facilitate the operation of tunnel management and control systems.

Refer to Section 2 of the *Smart Motorway Design Guide for Traffic Monitoring and Surveillance*[^5] for more detail on the use and general design principles of CCTV.

#### 3.3.1 Coverage and design principles

**3.3.1.1 Approaches to and downstream of tunnels**

At a minimum, full (100 per cent) CCTV coverage should be provided on the network outside the tunnel to support the tunnel closure management system and over-height vehicle management. Overlapping coverage (ie 200 per cent coverage with 100 per cent redundancy) may be considered where there is a need to view more than one area of camera coverage at the same time.

CCTV coverage on approach to and downstream of tunnels should include:

- Multiple CCTV cameras installed to monitor each tunnel portal (ie overlapping coverage)
- CCTV coverage of motorway mainline, entry and exit ramps affected by tunnel closure management devices, including:
  - advance warning signs/VMS
  - tunnel closure control points
  - moveable medians and in-pavement lights
  - median openings
  - other warning or control systems such as LUMS/VSL.
- CCTV cameras installed to provide visual confirmation of the display and operation of all tunnel closure and management devices
- Intersecting roads must be viewable from the motorway CCTV cameras for a minimum distance of 200 m from any motorway on or off-ramp. For the purpose of this section, intersecting roads are defined as roads intersecting any motorway entry ramps or exit ramps
- For each arterial road that approaches a tunnel portal, CCTV cameras should be considered at a location of up to one kilometre away from the tunnel portal
- CCTV coverage of tunnel diversion routes as required for tunnel emergency/incident management
- CCTV coverage of the entrances to tunnel motorway infrastructure service and control centre buildings external to the tunnel.
Additional requirements for arterial road coverage should be considered on a project-by-project basis.

### 3.3.1.2 Tunnel environments

Within tunnels, CCTV should provide overlapping coverage (ie 200 per cent coverage, 100 per cent redundancy) of the tunnel including the motorway carriageways, emergency stopping bays, emergency telephone locations, the full length of entry ramps, exit ramps and all electronic signs and traffic control devices (to allow visual confirmation of displays). Overlapping coverage allows more than one camera to view the same location.

Overlapping coverage may be provided through a combination of fixed and ‘pan, tilt and zoom’ (PTZ) cameras and may include the same cameras used in an automatic video incident detection (AVID) system if part of the tunnel design (refer to Section 3.4).

Coverage should meet the viewing requirements outlined in Section 2.3.1 of the *Smart Motorway Design Guide for Traffic Monitoring and Surveillance*[^5] and include coverage of:

- Motorway mainline including shoulders
- All exit and entry ramps within the tunnel
- Non-trafficable areas, including egress passages, cross-passage doors, crossover points, motorist emergency points including emergency telephones, emergency stopping/maintenance bays, emergency equipment cabinets, deluge zones and electronic sign displays (as required for tunnel emergency/incident management).

**Note** that further guidance in relation to CCTV coverage of non-trafficable areas is out of the scope of this guide, however CCTV placement may be required to service both traffic and other tunnel management functions.

Cameras should be faced downstream (ie so not directly facing tunnel air flow) to ensure that the camera lens remains clear, or otherwise a camera with lens-washing system should be used.

Figure 1 provides an example of CCTV coverage provided within a tunnel.

CCTV spacing will be affected by the type of camera, mounting height, line of sight, camera placement and carriageway alignment (eg considering horizontal and vertical curvature). Spacing should consider these factors in order to provide overlapping coverage. CCTV visibility should not be obstructed by other traffic management devices in the tunnel.
Figure 1: Example placement of CCTV and emergency telephones in a tunnel

Legend
- **Fixed camera**
- **Indicative fixed camera coverage**
- **PTZ camera**
- **Indicative PTZ camera coverage**
- **Cross passage**
- **TMS** Tunnel Message Sign
- **ESB** Emergency stopping / maintenance bay
- **Emergency telephone**

Notes:
Figure not drawn to scale.
Emergency telephones may be located on the near or far side of the tunnel. Refer to Section 3.5.1 of this guide for further guidance.
Refer to Section 0 of this guide for considerations regarding the need for emergency stopping bays within tunnels.
3.4 Automatic incident detection

Automatic Incident Detection (AID) is required in tunnels as there is a critical need for immediate response to incidents due to the higher safety risk in tunnel environments. Where an incident is detected the system will send an alert to the operator for verification.

In tunnel environments Roads and Maritime typically deploys AID systems which use analysis of video images from fixed cameras as detectors, known as Automatic Video Incident Detection (AVID) systems. These systems work more reliably in tunnel environments than in open air environments due to constant lighting conditions.

AID systems can also use other types of detection devices, such as loops, infrared, or microwave traffic detectors.


3.4.1 Coverage and design principles

Within tunnels, the AID system must provide full (100 per cent) coverage of the motorway and must immediately and accurately detect and report an incident at any location on the road.

Full coverage includes:

- Tunnel mainline including sealed shoulders
- All tunnel entry and tunnel exit ramps
- Tunnel emergency stopping bays.

The types of traffic incidents/events that should be detectable by the AID system include:

- Stopped vehicle
- Wrong way vehicle (reverse direction of travel)
- Speed change (under/over/sudden drop)
- Queuing vehicles (ie due to incident or congestion)
- Pedestrian on the road
- Fallen objects or debris etc.

Detection of non-traffic events (eg smoke and flame detection) may also be required as part of other tunnel management systems (out of scope of this guide).

Fixed cameras facing upstream should be used for AVID systems. Lighting requirements should be considered in the design of AVID systems.

Spacing of elements comprising AVID systems in tunnel environments should be driven by visibility requirements and may be impacted by factors such as tunnel height. Typical spacing is approximately 120 metres for fixed cameras used for AVID systems.
3.5 Emergency telephones

Emergency telephones are required in all tunnels to enable road users to directly contact operators or other designated responders to facilitate assistance or report incidents. They are particularly critical in tunnels to ensure timely reporting and response to incidents.

3.5.1 Spacing and design principles

The general design principles for emergency telephones as described in Section 4 of the *Smart Motorway Design Guide for Traffic Monitoring and Surveillance*[^5] should be applied for emergency telephones located on motorways upstream or downstream of a road tunnel, and also apply to motorways in road tunnels. If there are any differences in practice between this guide and the *Smart Motorway Design Guide for Traffic Monitoring and Surveillance*[^5], then this guide will apply.

Emergency telephones in motorway tunnels are typically located in Motorist Emergency Points (MEP) containing an emergency telephone and a fire extinguisher. Otherwise, they should be located in an emergency stopping bay. Due to the limited space available, emergency telephones and MEP in tunnels should generally be wall-mounted. Emergency telephones in tunnels must be suitable for use in the tunnel environment and must comply with the design and construction requirements for telephone communications equipment set out in AS 4428.4[^6], AS 1670.4[^7] and AS 60849[^8].

In motorway tunnels, emergency telephones should be placed at a nominal spacing of 60 metres with a 10 per cent tolerance. Typical spacing for emergency telephones is shown in Figure 1.

For tunnel carriageways with two or less lanes, emergency telephones should be placed on one side of the tunnel. This may be the near-side or far-side of the tunnel. The key locating principle should be to minimise the safety risk for motorists using the telephone. The location of emergency telephones in tunnels should also support the pedestrian emergency access plan.

For tunnel carriageways with three or more lanes, emergency tunnels should be placed on both sides of the carriageway to discourage the need for pedestrians to cross the carriageway. Where an emergency stopping bay is located (refer to Section 6.2), an emergency telephone should be located within the bay.

Emergency telephones should also be considered on any entry and exit ramps located within a tunnel environment.

3.6 Variable message signs and tunnel message signs

Variable Message Signs (VMS) are used as part of a motorway traveller information system to provide real-time information to motorists on downstream traffic conditions and travel time information to support informed route choices.

They are particularly important in advance of tunnel environments to provide warning of any incidents, congestion or other events occurring in the tunnel and to facilitate tunnel closure management (refer to Section 5).
In tunnel environments, smaller VMS, referred to as tunnel message signs (TMS) are required due to the constrained vertical clearance of the tunnel environment. TMS typically only provide one line of text and are used to support traffic management as well as to provide critical fire and life safety messages during tunnel incidents/closures.

### 3.6.1 Warrants

Variable message signs should be installed on the tunnel mainline carriageway and at arterial intersections at motorway interchanges as per the warrants in the *Smart Motorway Supplement for Traveller Information*[^9], and as required to support tunnel closure management and traffic diversion (refer to Section 5).

All tunnels require VMS at the tunnel portal and TMS at regular spacings within the tunnel based on the spacing requirements outlined in Section 3.6.2.

### 3.6.2 Spacing and placement

#### 3.6.2.1 Approaches to tunnels

VMS on tunnel approaches provide advance warning to motorists of downstream conditions within the tunnel. They should be located before key decision points to facilitate traffic moving onto diversion routes and prevent traffic from entering a tunnel during an incident.

VMS should be provided, as a minimum:

- Before the last decision point before a tunnel diversion route, positioned at a sufficient distance upstream to provide adequate warning to motorists and enable safe diversion of traffic
- At the tunnel portal, directly above the entrance.

For high volume urban motorways, traveller information should start well in advance of the last exit in order to facilitate diversion of traffic over a wider area. One exit is unlikely to be able to handle traffic for a full motorway closure. This needs to be considered in the emergency/incident management planning for a tunnel facility.

VMS should be provided on arterial road approaches to the tunnel to warn and redirect traffic before vehicles join entry ramps (refer to the *Smart Motorway Supplement for Ramp Metering Signals*[^10]).

Consideration should also be given to whether VMS will be required to support over-height vehicle management systems (refer to Section 3.7).

Typical placement of VMS on the approach to a tunnel diversion route and on the approach to a tunnel portal are shown in Figure 9 and Figure 10 in Section 5, in the context of a tunnel closure scenario.

For further design guidance on the application of VMS on motorways, refer to the *Smart Motorway Supplement for Traveller Information*[^9] and the *Guidelines for the Location and Placement of Variable Message Signs*[^11].
3.6.2.2 Tunnel environments

TMS should be located along the entire length of the tunnel between VSL/LCS to maximise the view of a downstream TMS during incidents. TMS should also be provided on entry ramps into a tunnel environment.

TMS should be overhead mounted in tunnel environments. Spacing of TMS is typically 120 metres when TMS are alternately located with VSL/LCS in a tunnel.

For long underpasses less than 120 metres in length, TMS may be limited to the tunnel portal and prior to the tunnel exit or as otherwise determined by operational requirements for tunnel emergency/incident management.

For tunnels between 120 metres and 240 metres the requirement for mid-tunnel TMS should be considered on a case-by-case basis based on the principles outlined in this design guide and operational requirements for tunnel emergency/incident management.

For further guidance, refer to the discussion on spacing provided in Section 7.4.1. Figure 8 in Section 4.3 shows an example of typical spacing for TMS alternately placed with VSL/LCS.

3.6.3 Sizing

Further guidance on the sizing of VMS on the approaches to and downstream of tunnels is provided in the Smart Motorway Supplement for Traveller Information[9]. The sizing of VMS located at the tunnel portal should be based on the standard size for the speed environment.

Due to the constrained road environment within tunnels, TMS are typically limited to a single line display (eg 200 millimetres character height and 18 character length).

3.7 Over-height Vehicle Management

Over-height vehicle management should be considered to manage the risk of over-height vehicles on the approaches to tunnels, as described in Section 2.2.2.2.

3.7.1 Warrants

The Smart Motorway Guidelines[2] determine that over-height vehicle management systems should be subject to a separate business case. They must be considered for implementation in advance of all motorway tunnels.

3.7.2 Assessment and Selection of Measures

The type of detection systems, warning signs and control systems incorporated within an over-height vehicle management system should be assessed for each project based on identification of suitable measures to limit the risk of over-height vehicle collisions at that particular location. Mitigation measures may consist of a range of passive and active measures. Active measures include over-height detection and warning systems, in-vehicle alerts and infrastructure alterations. Passive measures include static traffic signs, road markings, protection of the structure and driver education.

An assessment of measures to manage over-height vehicles may include:
• A site assessment to consider:
  − The level of risk that a collision might occur (e.g., crash history, sight distance to low clearance structures, number of over-height vehicles using the route, existing traffic signs, availability and feasibility of detour route options, accessibility options for emergency vehicles and the effectiveness of heavy vehicle detour signs, i.e., historical levels of non-compliance)
  − The severity of impact if a collision does occur (e.g., type of structure, traffic volumes, number of over-height vehicles carrying dangerous goods, impact on safety and traffic flows).

• Identification of contributory factors in over-height vehicle collisions such as lack of awareness of vehicle height or the presence of a low clearance structure, ignorance or incomprehension of traffic/redirecting signs, and insufficient conspicuity of a low clearance structure

• Selection of the most practical, economical, effective and reliable mitigation measures with multiple redundancies.

Effective over-height vehicle management is likely to require a combination of mitigation measures as described in Section 3.7.3.

The general principle is that the over-height vehicle management system should help to avoid infrastructure damage while maximising safety and minimising traffic impact.

The proposed approach should consider that the further in advance the over-height vehicle can be diverted (without significantly adversely impacting its total journey time), the smaller the likelihood of a lane/road closure being required.

In tunnel situations, the design of over-height vehicle systems should consider requirements for tunnel portal management (e.g., to implement tunnel closures), which may utilise similar warning and control systems. Where possible, system design should be flexible to address operational needs. Further detail about tunnel closures is provided in Section 5.

In addition to the mainline, over-height vehicle detection and warning may also be required on the arterial road approaches and entry ramps to motorway tunnels.

3.7.3 Design principles

3.7.3.1 Overview of measures

An over-height vehicle management system may consist of the following core components:

• Over-height vehicle detection placed before and after the last exit or diversion point prior to a low-clearance tunnel entry (refer to Section 3.7.3.2)
• Over-height motorist warnings, eg an activated VMS sign, before and after the last exit or diversion point, to notify users in advance of a structure that their vehicle exceeds the maximum permissible dimensions and identify necessary road user actions (eg divert at exit before the structure) (refer to Section 3.7.3.3). Warnings on multi-purpose VMS may require the system to detect the over-height vehicle licence plate number and then display on the VMS in order provide a specific instruction to the over-height vehicle driver. This may have implications for the detection technology selected.

• Over-height vehicle control (eg boom barrier/swing gate and/or traffic light control) after the last exit and/or at the tunnel entrance to prevent vehicles that have ignored the warning messages from proceeding under the structure, as well as to manage other traffic in the event of a road closure (refer to Section 3.7.3.4).

• A median opening after the last exit and before the structure/tunnel portal to facilitate U-turning of stopped over-height vehicles at the control point (also refer to Section 3.7.3.4).

An example application of an over-height vehicle management system is shown in Figure 2. For this system set-up, when an over-height vehicle is detected on the mainline or the entry ramp at the first detector, then a warning is displayed on the next downstream mainline VMS instructing the driver to leave via the most appropriate exit prior to the tunnel. An alert is also sent to the operator. If the driver ignores the warning and continues, then it is detected by the second set of over-height vehicle detectors just after the exit ramp and another warning message is displayed on the next downstream VMS. The system may then activate the tunnel closure system in order to physically stop the over-height vehicle from entering the tunnel and to protect the other road users.

Some of the components of an over-height vehicle management system may also be used to support other functions. For additional guidance, refer to the following sections of this guide:

• Tunnel closure control and median openings (refer to Section 5.4) – provides the same function as over-height vehicle control

• VMS (Section 3.6).
Figure 2: Example of over-height vehicle management system on tunnel approach

Legend

- **OR** Over-height restriction static signs
- **OD** Over-height vehicle detector
- **VMS** VMS for over-height vehicle warning
- **OP** Over-height vehicle protection barrier

Notes:
Figure not drawn to scale.
3.7.3.2 Over-height vehicle detection

As a minimum, over-height vehicle detection consists of:

- A first detector site located before the last exit ramp/over-height vehicle diversion point to proactively notify drivers to divert and alert tunnel operators of an approaching over-height vehicle.

- A second detector site located after the last exit/diversion point, which confirms if an over-height vehicle has not diverted and is travelling towards a low-clearance structure, prompting further actions by tunnel operators.

Additional detector sites may be required depending on the selection of warning and control measures.

Over-height vehicle detector sites should be placed so that there is sufficient time for a warning message or control measures to be activated and for legibility requirements to be met. For further guidance, refer to the Austroads Guide to Traffic Management Part 10: Traffic Control and Communication Devices[12].

Over-height vehicle detection should be capable of detecting over-height vehicles in all traffic lanes approaching a low-clearance structure, in the direction of travel to which the detector applies.

Existing over-height vehicle detection systems used by Roads and Maritime consist of over-height vehicle detection dangles and infra-red detectors. Other available technologies include laser beams (refer to Figure 3), photoelectric sensors and Automatic Number Plate Recognition (ANPR). The latter technology enables display of licence plates on VMS to provide specific instructions to the driver of a non-compliant vehicle, which may help to improve compliance.

As per other types of vehicle detectors, over-height vehicle detectors should be capable of working in all motorway environmental conditions and speed environments. When setting the detection height, allowances should be made for the camber of the road to ensure that any vehicle that is above the maximum allowable height will be detected regardless of which lane it is travelling in. The detector should be able to adjust to different heights.
3.7.3.3 Over-height vehicle warning

An over-height vehicle warning system should include high visual impact warning signs dedicated to advising drivers of over-height vehicles. Warning signs should be located to provide drivers with opportunities to detour from the motorway route or with adequate space to stop before reaching a structure.

All warning devices should be positioned and mounted so that they are clearly visible to approaching vehicles in any lane.

Static signing practices

A low clearance structure is defined as a structure that has a clearance height of less than 4.6 m. These structures must display a regulatory sign ‘LOW CLEARANCE X.Xm’ on the structure over the centre of the road, where ‘X.Xm’ is the safe clearance height for vehicles (refer to Figure 4). If a detour is available, clear detour signs should be provided to safely direct over-height vehicles. Examples are shown in Figure 5 (Lane Cove Tunnel) and Figure 6 (Sydney Harbour Tunnel). Warning signs are also provided on the approach to low-clearance structures (refer to AS1742.2-2009 and AS 1742.3-2009).
Figure 4: Regulatory sign for low clearance structures

![LOW CLEARANCE](image)

R6-11 regulatory sign

Figure 5: Static signs for over-height vehicles from Lane Cove Tunnel

![Lane Cove Tunnel](image)

W3-206 low tunnel clearance sign (example from Lane Cove Tunnel)

Source: Roads and Maritime Traffic Signs Database

Figure 6: Example of over-height vehicle signing on the approach to the Sydney Harbour Tunnel

![Sydney Harbour Tunnel](image)
Flashing signs and variable message signs

Upstream of the last exit before a low clearance structure, over-height vehicle detection may be used to activate a flashing sign (ie static sign with flashing lanterns in the corners) and/or VMS to notify over-height vehicles of the need to use a detour (refer to Figure 3 and Figure 7). Flashing signs and VMS should be located a sufficient distance upstream from motorway exits providing access to applicable detour routes. VMS located before the structure or the tunnel portal entrance should advise drivers of over-height vehicles to stop and not to proceed any further.

Where the same requirements apply, the VMS used on tunnel approaches for other smart motorway and tunnel emergency/incident management functions may also be used for over-height vehicle warning (refer to Section 3.6).

Figure 7: VMS directing over-height vehicle to a detour route

3.7.3.4 Over-height vehicle control

In practice, signing and warning measures alone do not always deter drivers of over-height vehicles from entering low clearance structures.

Over-height vehicle control should be located in front of major structures such as tunnels to stop non-compliant vehicles. Control systems must be located a sufficient distance downstream from the previous warning system to detect a non-compliant vehicle and activate the control systems to prevent its entry into the tunnel.

Provision must also be made in the design to allow for diversion of over-height vehicles. Where the same requirements apply, tunnel closure control points and median openings may be used for over-height vehicle control (refer to Section 5.4).

3.7.3.5 Other measures

A number of other measures can also be installed to reduce the risk and/or impact of low clearance incidents or to improve incident management, including:

- Impact detectors to measure the degree and level of impact on the structure
- Permanent physical barriers and sacrificial structures (eg detachable protection beams) may be installed on or in front of the low clearance structure to minimise damage by the vehicle whilst also minimising road safety risk for other road users
- CCTV to allow tunnel operators to monitor the progress of over-height vehicles within the vicinity of the low clearance structure and if required activate a control response, ie in the event the vehicle fails to stop prior to a diversion route (refer to Section 3.3)
• Reflective surfaces, markings and use of colour to improve visibility of the structure

• Parking areas to temporarily store over-height vehicles that have ignored the warning signs, to minimise the impact on traffic flows while the vehicle is waiting for assistance to divert

• Innovative measures to encourage an over-height vehicle to stop in advance of the tunnel

• Enforcement systems to improve driver compliance, ie vehicle detectors alert enforcement cameras of the presence of a non-compliant heavy vehicle.

Improved sight distance and visibility of structures can also improve driver awareness of the existence of a low clearance structure ahead.

3.7.4 Complementary material

Further standards can be found in the Roads and Maritime Over-height Detection System Operations and Maintenance Manual\(^{28}\).

Further information on over-height vehicle management systems is provided in the following ARRB research reports for Roads and Maritime:

- *Static and Active Signposting to Divert Overheight Vehicles Around Low Clearance Structures – literature review*\(^{15}\)
- *Static and Active Signposting to Divert Overheight Vehicles Around Low Clearance Structures – Best Practice Methodologies*\(^{16}\).
4 Traffic control elements

4.1 Overview

Smart motorway control elements provide operators with the ability to proactively optimise traffic flow parameters and improve road user safety, particularly during periods of high demand and incidents. Based on the warrants in the following sections, these control elements should be applied within and upstream/downstream of tunnel environments to provide seamless operations along a smart motorway route.

This section includes the following smart motorway control elements:

- Ramp metering signals (Section 4.2)
- Lane Use Management System (LUMS) including VSL (Section 4.3).

4.2 Ramp metering signals

Ramp metering of entry ramps on approach to and within tunnel environments is critical for maintaining optimal mainline flow and preventing (or minimising) the occurrence of flow breakdown and congestion on the motorway mainline, including within the tunnel.

Ramp metering at motorway interchanges in tunnels would provide similar benefits to locations outside of tunnels and facilitate the smart motorway route to be managed as a whole, including the ability to manage and balance ramp queues along the route.

Ramp metering signals on tunnel interchange ramps would:

- Support management of traffic during non-recurrent congestion (e.g. restricting traffic upstream of an incident and/or tunnel closure)
- Dynamically respond to changing traffic demands within the tunnel and on entry ramps and activate and deactivate as necessary
- Be manually deactivated by an operator when required to assist with incident management and emergency access
- Facilitate communication with the surrounding arterial network via SCATS to implement strategic plans (i.e. access to and egress from the tunnel).

4.2.1 Warrants and design principles

The same warrants and design principles that apply for traffic engineering design and operation for open air conditions also apply to partially covered or fully covered entry ramps. For further guidance, refer to the Smart Motorway Supplement for Ramp Metering Signals[^10] and the Smart Motorway Design Guide for Priority Access Lane for Entry Ramps[^17].

If a coordinated ramp metering is used then all entry ramps, including those in tunnels, must have ramp metering traffic signals for effective control.

Ramp signals may still be considered for an entry ramp within or upstream of a tunnel on the basis of operational requirements for emergency/incident management (i.e. to enable ramp closures as part of the tunnel closure management system – refer to Section 5), even if the entry ramps do not meet other Roads and Maritime warrants for ramp metering signal installation.
4.2.2 General Design considerations

If traffic is queued on a ramp due to ramp metering signal operation, this is similar to queued traffic on entry ramps where there is no ramp signalling. The advantage of the scenario with ramp metering signal operation is that the queues will be monitored and managed, and mainline flow will be maintained and congestion and queues greatly minimised. In this scenario, if emergency services need to access the motorway via an entry ramp being metered, the ramp signals can be overridden by an operator to allow immediate passage of an emergency vehicle. This will release the local queue if spare capacity is available downstream of the ramp metering stop line. VMS on the arterial road and entry ramp would then be used to indicate that the ramp was closed to prevent additional vehicles from entering the ramp.

The design for ramp storage to support ramp metering operation should be determined for each location/project to consider whether storage is built inside or outside of the tunnel environment. Design for storage should be economically sound and demonstrate net benefit, considering that the cost of building underground may be offset by other benefits such as reduced community impact and requirements for land acquisition/surface works as well as the associated ongoing network performance complications (eg interference with arterial operation). Consideration should also be given to the impact on air quality and tunnel safety management.

The road design requirements (eg merge/acceleration lengths and queue storage) for tunnel entry ramps are the same for standard entry ramps. Design compromises against standards within tunnels can seriously compromise safety or operational performance and may increase the likelihood of flow breakdown and incidents due to tunnel congestion, resulting in further delays and potential closures.

However, if deviations from standard are considered as a result of a significant design constraints, then the following considerations apply:

- If the acceleration distance to the merge is increased beyond the recommended design standard (ie to enable signals to be located outside of the tunnel entrance), then the design should ensure that this does not result in bunching of merging vehicles that would reduce the effectiveness of ramp metering operations.
- If ramp storage is compromised significantly as a result of deviation from the design standard, then additional compensating storage may be required elsewhere in the system.

The design of warning and regulatory signs to support underground ramp metering signals and advise or direct motorists about tunnel and ramp closures has the same considerations as surface treatments, for example in relation to visibility. All underground ramp metering signal installations should have the same functionality and ‘look and feel’ as surface treatments to ensure a consistent driver experience along the motorway route (refer to Section 2.2.2.3).

The Smart Motorway Supplement for Ramp Metering Signals provides more detailed guidance on geometric design and device layout for ramp metering signal layout.
4.3  **LUMS and VSL**

Lane Use Management Systems (LUMS) including Variable Speed Limits (VSL) are smart motorway elements used to improve traffic flow and safety, particularly when there are incidents and heavy congestion. They may also be installed on tunnel approaches to reinforce the current tunnel operating conditions for motorists and assist with lane closure and speed reduction transitions in advance of tunnel closure control points (refer to Section 5.4).

LUMS and VSL installed downstream of a tunnel will assist with managing traffic to minimise the operational risk of downstream operations impacting on traffic inside the tunnel.

LUMS and VSL also help to manage the additional safety risks within tunnels. In most cases, a tunnel will not have a shoulder or will have a reduced width shoulder, which increases the importance of lane and speed management during an incident.

Roads and Maritime practice for smart motorways is to use integrated Variable Speed Limits (VSL) and lane control signals (LCS) including in road tunnels. This will provide a seamless operating environment and consistent driving experience with adjacent sections of motorway where VSL/LCS are installed.

VSL/LCS may also be used to operate reversible or dynamic lane systems in tunnels. These may have specific design requirements that are not covered in this guide and should be assessed on a per project basis.

Additional information on warrants and design is provided in the *Smart Motorway Supplement for LUMS including VSL*[^18]. VSL/LCS should also comply with the requirements of *IC-QA-TS105 ITS Electronic Message Sign Site*[^19].

4.3.1  **Warrants**

Variable message signs should be installed on the mainline carriageway (upstream and downstream of the tunnel) as per the warrants in the ‘*Smart Motorway Supplement for LUMS including VSL*[^18]’, and as required to support tunnel closure management (refer to Section 5) and provide a continuous traffic management scheme along the motorway route.

All tunnels require VSL/LCS located at the tunnel portal and immediately prior to the exit, as well as mid-tunnel VSL/LCS based on spacing requirements in Section 4.3.2. Requirements for mid-tunnel VSL/LCS in shorter tunnels (< 120 m, ie long underpasses) may vary depending on the tunnel length and location of tunnel cross-passages (refer to Section 4.3.2.2).

4.3.2  **Spacing and placement**

4.3.2.1  **Approaches to and downstream of tunnels**

Refer to the *Smart Motorway Supplement for LUMS including VSL*[^18] for further guidance on appropriate spacing and placement of VSL/LCS on the open mainline carriageway. VSL/LCS must also be located on entry ramps on the approaches to tunnels.
The number and location of VSL/LCS sites required upstream of the tunnel portal to support the tunnel closure management system is dependent on:

- The total number of carriageway lanes
- The number of speed and lane use transitions required to close the full carriageway
- The location of the tunnel closure control/stopping points.

For example, a four lane to one lane reduction requires up to three steps where single, sequential lane closures are used.

Figure 9 and Figure 10 in Section 5 provide examples of VSL/LCS spacing and placement on motorway mainline approaches to tunnels based on these guidelines and in the context of a tunnel closure scenario.

**4.3.2.2 Tunnel environments**

VSL/LSC must be placed at the tunnel portal entry and immediately before each of the tunnel exit portals and then should be regularly spaced along the length of the tunnel.

The spacing and placement of VSL/LCS should consider:

- The need to manage tunnel closures and incidents
- The viewing distance and legibility requirements of VSL/LCS to maximise motorists view of a downstream signal array
- Where alternating VSL/LCS and TMS are provided, the spacing for the element with a shorter viewing distance should determine the spacing of both elements, to avoid co-location issues and to provide a consistent driving environment.

For tunnels where alternating VSL/LCS and TMS are provided, a typical placement and spacing of VSL/LCS is 120 metres, with the VSL/LCS placed at the tunnel cross-passage locations. Figure 8 provides an example of this type of a layout.

Based on these spacing and placement principles, long underpasses that are less than 120 metres in length may not require additional VSL/LCS beyond those at the tunnel portal entry and immediately prior to the exit portal. If a cross-passage is provided in tunnel short or long underpass, a VSL/LCS may be provided at the location of the cross-passage.

For tunnels between 120 metres and 240 metres the requirement for mid-tunnel VSL/LCS should be considered on a case-by-case basis based on principles outlined in this document and tunnel operational requirements.

Locating the VSL/LCS at cross-passage locations will allow the control of traffic via the lane control signals to be aligned with the need to evacuate motorists via cross-passage evacuation routes. The 120 metres spacing will maximise a motorist’s view of downstream signal arrays whilst also considering the viewing requirements of VSL/LCS and TMS. These issues are further discussed in Section 7.4.

Consideration should also be given to any sight obstructions that may limit sign visibility (eg horizontal or vertical curvature and positioning of other devices). VSL/LCS must be mounted over each carriageway lane.
Consideration should be given to maintenance implications when locating signs to ensure that maintenance functions can be performed safely with minimal traffic disruption.

VSL must also be provided on all entry ramps into a tunnel to communicate the mainline operating speed to motorists.

### 4.3.3 Sizing

Refer to the *Managed Motorway Supplement for LUMS including VSL*\(^{[18]}\) for guidance on appropriate sizing of VSL/LCS on the open mainline carriageway.

The size of VSL/LCS signs in tunnel environments is governed by the speed limit and should be able to generate the speed limit in accordance with AS 1743-2001\(^{[20]}\) for R4-1 signs. VSL/LCS sign size requirements in tunnels are shown in Table 2.

<table>
<thead>
<tr>
<th>Sign type</th>
<th>Signal size requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>VSL/LCS and VSL only(^1)</td>
<td>‘B’ size signs 600 mm wide red annulus are to be used in tunnels for smart motorways.</td>
</tr>
<tr>
<td>LCS(^1)</td>
<td>The desirable minimum size of LCS in tunnels is 300 mm (200 mm minimum).</td>
</tr>
</tbody>
</table>

\(^1\) *Where integrated VSL/LCS are not practicable due to site constraints.*

Future tunnels should desirably be designed to accommodate the ‘B’ size VSL/LCS signs and still provide the required vertical clearance for traffic.

For existing tunnels, separate VSL signs and LCS may have to be considered due to site constraints that mean a VSL sign above each lane cannot be accommodated. In these cases, LCS should be provided over each lane and VSL may be side-mounted. This is not the preferred option due to inconsistency with the VSL/LCS used upstream/downstream of the tunnel.

Roads and Maritime approved VSL/LCS design has functionality for flashing annulus but no flashing amber conspicuous lights. If there are existing devices on the carriageway on approach to the tunnel these should be upgraded to the approved VSL/LCS design.

Refer to the *Managed Motorway Supplement for LUMS including VSL*\(^{[18]}\) for guidance on use of static regulatory signs in VSL/LCS environments.
Figure 8: Smart motorway element spacing within a tunnel

Legend

- **ESB**: Emergency stopping / maintenance bay
- **Cr**: Cross passage
- **TMS**: Tunnel Message Signs

Notes:

- Figure not drawn to scale.
- Other smart motorway elements that would be expected to be included, but have not been shown on the diagram, include ramp metering signals, vehicle detection, CCTV, automatic incident detection and emergency telephones. Other warning and regulatory signing may also apply.
5 Tunnel closure management

5.1 Overview

Tunnel closures may be required for a variety of reasons such as:

- During an emergency (eg flood, fire) or traffic incident within the tunnel
- During periods of tunnel maintenance
- At times when congestion may threaten to overload a tunnel’s ventilation system
- When an over-height vehicle fails to divert from the motorway before the tunnel.

As discussed in Section 2, smart motorway elements for tunnel environments should aim as first priority to maintain safe and efficient traffic flows at all times. In many cases the design principles for specific smart motorways elements are the same for tunnels as for other locations.

This section identifies where there may be additional considerations in design of smart motorway elements in order support management of tunnel closures.

Tunnel closure management requires a variety of smart motorway elements working together to prevent vehicles from entering a tunnel while minimising the safety and operational impacts on the surrounding road network as a result of the closure. The design of systems used for tunnel closure should consider the key design considerations and operational requirements for tunnel emergency/incident management that are identified in Section 2.2.2.1.

This section defines the traffic management requirements to support tunnel closure management (Section 5.2), provide examples of integrated use of smart motorway elements on tunnel approaches and near tunnel portals (Section 5.3) and details design guidance in relation to tunnel closure control points and diversion measures (Section 5.4).

5.2 Traffic management requirements

Traffic management requirements for tunnel closure management include:

- Detecting and verifying tunnel incidents and their location
- Stopping and diverting traffic at locations in advance of a tunnel
- Alerting approaching motorists to the need to stop, divert or to other changing conditions
- Closing carriageway lanes approaching a tunnel (for a partial or complete closure)
- Closing motorway entry ramps on approach to the tunnel
- Altering lane configurations to enable motorists to use a diversion or turn-around facility
- Managing motorists’ speeds on approach to and throughout the closure
• Reopening the closed carriageway lanes and entry ramps at the conclusion of a tunnel closure and implementing higher speed limits (as appropriate for operational conditions)

• Allowing motorway operators to monitor traffic conditions and tunnel closure management systems.

Tunnel closure management systems should be able to deal with incidents of escalating seriousness; for example, manage a single lane closure up to a full carriageway closure.

Over-height vehicle management (refer to Section 3.7) may also be integrated with tunnel closure management systems that assist with managing traffic in the event of an over-height vehicle striking a tunnel structure.

5.3 Examples of smart motorway elements on tunnel approaches

Figure 9 and Figure 10 show examples of smart motorway elements applied to facilitate the control of traffic approaching a tunnel during a closure event. These elements are further discussed in the sections that follow.

5.3.1 Smart motorway elements on approach to a tunnel diversion route

Figure 9 shows an example of smart motorway elements on the approach to a tunnel diversion route located at a motorway exit ramp (for Direction 1). Key features include:

• During a tunnel closure, traffic travelling in Direction 1 would be controlled by the tunnel closure traffic signals and stop line, which allow the moveable median to be positioned and in-pavement lights activated to facilitate diversion of traffic onto the motorway exit ramp (for further guidance, refer to Section 5.4)

• The tunnel closure would be supported by the integrated VSL/LCS located upstream and downstream of the stopping point, which guide traffic into diversion route lane configurations and manage speeds (refer to Section 4.3)

• VMS located upstream of the stopping point provide a means of alerting motorists to the tunnel closure and the need to divert to the alternate route (refer to Section 3.6)

• For Direction 2, the VSL/LCS assists with managing speeds or lanes for traffic exiting the tunnel and travelling further downstream

• Regularly spaced emergency stopping/maintenance bays (refer to Section 6.2) and advance exit signs are also indicated in relation to the spacing and placement of the VSL/LCS and VMS gantries.

Other smart motorway elements that would be expected to be included on the approach to a tunnel diversion route, but have not been shown in Figure 9 include:

• Ramp metering signals on entry ramps (Section 4.2)

• Vehicle detection (Section 3.2)

• CCTV for traffic surveillance (Section 3.3)

• Automatic incident detection (Section 3.4)
• Emergency telephones (Section 3.5)
• Over-height vehicle management systems (Section 3.7).

There may also be a requirement for management of traffic on upstream adjacent motorways to support tunnel closure management. This may require integrated operations across operational boundaries on the motorway and arterial road network.
Figure 9: Smart motorway elements on the approach to a tunnel diversion route

Legend
- Exit direction sign
- Emergency stopping / maintenance bay
- Advance exit sign

Notes:
- Figure not drawn to scale.
- Smart motorway elements apply to both directions of travel unless indicated otherwise.
- Distance to the next upstream VSL/LCS gantry for Direction 1 will be dependent on the layout of the motorway and factors such as the distance to the next motorway interchange.
- Other smart motorway elements that would be expected to support motorway operation, but have not been shown on the diagram, include ramp metering signals, vehicle detection, CCTV, automatic incident detection, emergency telephones and over-height vehicle management. Static/flashing advance warning signs may also be required to support operation of the tunnel closure control point and moveable median.
5.3.2 Smart motorway elements near the tunnel portal

Figure 10 shows an example of smart motorway elements on the approach to a tunnel portal (for Direction 1). Key features include:

- Tunnel closure traffic signals, a stop line and boom gates provided just upstream of the tunnel portal to prevent traffic from entering the tunnel during a closure (refer to Sections 5.4.2 and 5.4.3)
- A median opening located between the boom gates and tunnel portal to facilitate emergency vehicle and incident operator access to the tunnel and provide a mechanism for diverting traffic to the opposite carriageway during a tunnel closure (refer to Section 5.4.4)
- VSL/LCS provided in open-air and tunnel environments and located as follows (refer to Section 4.3):
  - Upstream of the tunnel closure stopping point (Direction 1) to assist in implementation of transitional speed reductions, lane closures and tunnel closure diversion routes upstream of the portal during all operating conditions and to assist the tunnel closure signals with stopping traffic during a closure
  - At the tunnel portal to indicate operating conditions within the tunnel
  - Within the tunnel at regular spacing to assist with managing speed and lane closures within the tunnel
  - Downstream of the tunnel (Direction 2) to manage speed and lane closures in order to minimise the risk of downstream conditions influencing operation within the tunnel.
- VMS and tunnel message signs (TMS) including (for further guidance, refer to Section 3.6):
  - VMS located on the approach and at the tunnel portal to alert drivers of a tunnel closure and/or otherwise provide advice on tunnel operating conditions
  - Regularly spaced TMS within the tunnel to allow tunnel operators to communicate important life safety information to motorists on how to respond during a tunnel emergency/incident.
- Regularly spaced emergency stopping/maintenance bays (refer to Section 6.2).

Other smart motorway elements that would be expected to be included near a tunnel portal, but have not been shown in Figure 10 include:

- Ramp metering signals on entry ramps (Section 4.2)
- Vehicle detection (Section 3.2)
- CCTV for traffic surveillance (Section 3.3)
- Automatic incident detection (Section 3.4)
- Emergency telephones (Section 3.5)
- Over-height vehicle management systems (Section 3.7).
Figure 10: Smart motorway elements near the tunnel portal

Notes:
Figure not drawn to scale.
Smart motorway elements apply to both directions of travel unless indicated otherwise.
Distance to the next upstream VSL/LCS gantry for Direction 1 will be dependent on the layout of the motorway and factors such as the distance to the next motorway interchange.
Other smart motorway elements that would be expected to be included on this section of motorway, but have not been shown on the diagram, include ramp metering signals, vehicle detection, CCTV, automatic incident detection and over-height vehicle management. Static/flashing advance warning signs may also be required to support operation of the tunnel closure control point and median opening.
5.4 Design principles for tunnel closure control points and diversion measures

5.4.1 Overview

Tunnel closure control points are required on the approaches to tunnels in order to:

- Support the diversion of traffic upstream of a tunnel (eg to implement a tunnel closure diversion route)
- Physically prevent traffic from entering a tunnel during a closure.

The specific location of tunnel closure control points should be determined on a site-by-site basis and will depend on:

- The layout of the motorway approaching the tunnel
- The availability of features to provide diversion and turn-around facilities
- The proximity of the tunnel portal to motorway exits located further upstream
- Road user and tunnel safety considerations ie enabling safe management of traffic during an emergency or incident.

Traffic control should be provided for all motorway mainline lanes and other ramp access points into a tunnel. They should be used in relation to approved diversion routes for tunnel emergency/incident management.

Examples of tunnel closure control points are shown in Figure 9 (approaching a tunnel diversion route) and Figure 10 (approaching a tunnel portal).

A control point should be located just upstream of a tunnel portal, consisting of the following components, as a minimum:

- A traffic signal aspect mounted above each carriageway lane (refer to Section 5.4.2)
- A boom gate, swing gate or equivalent that can close all carriageway lanes (refer to Section 5.4.3)
- A stop line painted onto the carriageway just before the boom gate and signals
- Appropriate warning and regulatory signs in advance and at the stopping point.

As determined by the operational requirements for tunnel emergency/incident management, a median opening may be required in the vicinity of the control point (refer to Section 5.4.4). Operators must also have the ability to stop traffic on the opposing carriageway to support operation of the median opening and U-turning of vehicles and therefore tunnel closure control must be provided outside all tunnel entrances.

The location of the control point and median openings should consider:

- The need to minimise the number of vehicles from entering the tunnel when it is not safe to do so
• The requirements of emergency vehicle and incident operators to access the tunnel
• The need for facilities at tunnel entrances such as emergency vehicle parking and staging areas
• The operational requirements for diverting traffic to the opposing carriageway
• The need to maintain road user safety in the event of a fire, flood or other emergency within the tunnel.

An additional advance stopping point may be required further upstream of a tunnel if a diversion route is located near a tunnel or has been identified in a tunnel’s emergency management plan as a tunnel diversion point. For example, this may occur at the last exit ramp before the tunnel. The advance stopping point is typically required upstream of a movable median and in-pavement lights to stop traffic whilst alternate lane configurations are implemented (refer to Figure 9 and Section 5.4.5).

Advance warning signs and LUMS/VSL may be used to inform motorists of changes to the road layout ahead. This type of advance stopping point does not require a boom gate.

Control of access at motorway entry ramps upstream of the tunnel can be provided through the use of ramp metering signals (refer to Section 4.2). In the event of a tunnel closure, the ramp metering system and associated traveller information signs can divert vehicles on the arterial approaches and prevent additional vehicles from entering the motorway. They can also assist with providing emergency vehicle access via the entry ramp to the motorway.

Further description of the components that are used to support tunnel control are described in the sections that follow.

5.4.2 Tunnel closure traffic signals

Traffic signals should be used to stop traffic at a tunnel closure control point. Tunnel closure traffic signals should be provided with red, yellow and green display aspects mounted above each of the lanes and should be accompanied by R6-6 ‘Stop here on red signal’ signs.

Under non-incident traffic operations, the signals are normally off and are only activated when necessary to close the carriageway.

Traffic control signals must conform to the Roads and Maritime Traffic Signal Design guidelines[21]. A white stop line must be provided on the carriageway surface at traffic control signals in compliance with the regulatory traffic signal compliance conditions.

The need for static warning signs and flashing lights in advance of the traffic signals should also be considered. For further guidance, refer to the Roads and Maritime Traffic Signal Design guidelines[21].

5.4.3 Tunnel closure boom gate

Tunnel closure boom gates are required at tunnel closure control points located in advance of the tunnel portal for mainline or ramp entrances, but are not required at control points provided to support operation of a moveable median.
The boom gate should be of the raise/lower type or as horizontal swinging barriers. The boom gate barrier should incorporate the following features:

- When in the ‘closure’ position, the boom gate is to always remain perpendicular to the traffic stream
- The barrier should be long enough to clearly indicate that the entry lane is blocked but designed such that it is possible for emergency vehicles to access the tunnel
- The boom gate should incorporate panelled sections that extend from boom gate arms to the road surfaces when the gates are closed and incorporate ability for boom gate arms to breakaway at vehicle impact speeds of greater than 10 km/h or bend and distort at lower speed impacts
- Red flashing lanterns included on the boom that are used to warn and stop motorists as the boom gate is lowered.

The barriers should be able to be controlled remotely by operators or manually by incident responders and maintenance crew. There must be sufficient advance warning to motorists via VMS and other signs to ensure the safe operation of the barrier.

5.4.4 Median opening

A median opening (refer to Figure 11) may be used to provide access for emergency services or tunnel incident operators and to provide a diversion facility for traffic stopped at the tunnel portal during tunnel closures.

*Figure 11: Median opening on the western approach to the Beecroft Tunnel on the M2 Motorway*

The need and exact location of tunnel closure control points and median openings may vary and should be developed to support the operational requirements for tunnels emergency/incident management and emergency vehicle access needs.
From a fire and life safety perspective, the median opening should preferably be located between the boom gate and the tunnel portal. This allows emergency services to approach a tunnel from the non-incident carriageway and cross over via the median opening, avoiding vehicles stopped at the tunnel closure stopping point. Figure 10 shows a median opening with this type of configuration.

A median opening should be located at a sufficient distance from the tunnel portals to allow a suitable staging and parking area for emergency services during incidents and to preserve road user safety when there is a fire or other emergency in the tunnel.

A median opening should provide countermeasures to prevent a vehicle from using the opening when they are not intended to or when it would pose a safety risk (eg via moveable or demountable barriers), while still allowing rapid deployment during an emergency/incident.

A median opening may also be used to support contra-flow or convoy operation. For further guidance, refer to the Austroads Guide to Road Tunnels Part 2: Planning, Design and Commissioning [3].

5.4.5 Moveable medians and in-pavement lights

Moveable medians and in-pavement lights are typically installed at more advanced locations upstream of the tunnel and are used to modify lane configurations and facilitate diversion of traffic off the motorway (eg onto an exit ramp) during closures. They are typically remote controlled and activated by operators when a lane or the tunnel is closed.

Moveable medians may only be re-positioned once approaching traffic has been stopped. This typically requires a tunnel closure control point (refer to Section 5.4) upstream of the moveable median and in-pavement lights. The control point typically consists of tunnel closure traffic signals and a stop line. However, boom gates are generally not required in advance of a tunnel diversion moveable median installation.

Warning must be provided to motorists in advance of the moveable median facility, to display the changed lane configuration to oncoming motorists whenever the moveable medians are in use to control or divert traffic. This may include static and/or electronic signs that must comply with Roads and Maritime signing practice.

Other smart motorway elements including VSL/LCS (Section 4.3) and VMS (Section 3.6) located upstream of the moveable median should be used to assist with slowing traffic down on approach, facilitating implementation of progressive lane closures and early merging of traffic into the exit lanes, as well as provision of advance information to motorists.

Both moveable medians and in-pavement lighting should provide for single lane and full carriageway closures.

In-pavement lighting is required to delineate alternate lane configurations that guide motorists out of the tunnel entrance carriageway lanes and through the turn-around facility or emergency exit.
The dimensions of the moveable median must be suitable for the traffic merge required to divert traffic from the lane(s) and should approximate a typical traffic median. Means must be provided to ensure that the moveable median travels within its design travel limits and is prevented from travelling beyond those limits. The sides of the moveable median facing oncoming traffic must have conspicuity flasher lights or raised retro-reflective marker panels to alert oncoming motorists to the position of the moveable median.
6 Other design considerations

6.1 Overview
This section provides guidance in relation to design of emergency stopping bays on motorway sections with tunnels (Section 6.2) as well as considerations relating to the retrofitting of smart motorway elements in tunnel environments (Section 6.3).

6.2 Emergency stopping bays
Emergency stopping bays (ESB) provide a space for a vehicle to stop clear of a traffic lane. In most cases, a tunnel will not have a shoulder or will have a reduced width shoulder, and therefore an emergency stopping bay may be required within the tunnel depending on tunnel length and the operational requirements for tunnel emergency/incident management.

6.2.1 Design principles
The general design principles for ESB as described in the Smart Motorway Design Guide for Traffic Monitoring and Surveillance[5] should be used to determine ESB requirements on the approaches to and downstream of tunnels.

The design of ESBs on the approach to a tunnel portal may also need to consider the requirements for over-height vehicles which may include the need to temporarily store over-height vehicles that have not complied with warning signs, to minimise the impact on traffic flows while the vehicle is waiting for assistance to divert.

In road tunnels, the need for ESBs should be determined on a case-by-case basis based on the requirements of a tunnels emergency/incident management planning and should consider the additional cost of providing increased tunnel cross-section against the operational risk of incidents and breakdowns. The co-location of ESBs with maintenance bays (e.g. at tunnel drainage sump and sub-stations) may assist with reducing the cost of providing ESBs in a tunnel.

An emergency telephone must always be provided in an ESB.

6.3 Retrofitting of smart motorway control elements
Even if the tunnel design traffic volumes do not meet the warrants for smart motorway control elements for the forecast year, in tunnel environments it is even more important to consider the need to future proof the design for retrofitting of smart motorway control elements at a later date. Physical and environmental constraints may restrict future options if provision is not made in the original design, for example, in relation to geometric design of entry ramps to support ramp metering requirements.

However, generally the spacing and layout requirements for smart motorways elements in tunnels are greater than for open motorway environments due to the additional safety and emergency/incident management considerations.

The application for smart motorway elements in tunnel environments should also consider requirements for enforcement, as detailed in Section 5 of the Smart Motorway Design Guide for Traffic Monitoring and Surveillance[5].
7 International Research

This section provides an overview of relevant international research that has informed the development of some of the design principles within this guide.

7.1 Tunnel Portals

Previous research has considered the importance of tunnel portals as a potential bottleneck location and other potential design implications at these locations. Research from Japan (Narisada & Yoshikawa)\(^{[22]}\) and the Netherlands (Broeren et al.)\(^{[23]}\) studied where drivers fix their attention on the approach to a tunnel. Drivers tend to start concentrating on the tunnel portal some 200 to 300 metres before the portal and all drivers are fixated on the tunnel entrance within the last 100 m to the portal.

Figure 12 shows the distribution of drivers fixated on the tunnel portal based on the distance from the portal.

*Figure 12: Driver fixation on the tunnel entrance as a function of the distance to the tunnel entrance*

![Graph showing driver fixation percentage over distance to tunnel entrance.]

Broeren et al.\(^{[23]}\) reviewed research by the Austrian Federal Ministry of Traffic, Innovation and Technology that analysed data from 1999 – 2003 for 136 Austrian tunnels, of which 110 tunnels had one-way traffic. The data revealed that the number of incidents was at its highest level at the tunnel entrance, and just past the entrance the rate appeared to be relatively low. The analysis found that near tunnel portals, the share of single vehicle incidents was relatively high with the share of multiple-vehicle incidents being more dominant elsewhere inside the tunnel (refer to Figure 13).
These results implied that tunnel portals had a significant level of influence over the driver’s thought processes and decision making, particularly as the next section of roadway will result in the need for heightened concentration levels as a result of the narrowing of the roadscape and the expected changes in lighting in the tunnel transition area. Therefore, other distractions to drivers within this critical zone such as lane changing and merges/diverges and speed limit changes need to be minimised.

Additionally, the capacity of drivers to make several decisions simultaneously or in rapid succession imposed conditions on the minimum distances that should be maintained between driver decision and action points.

### 7.2 Vertical Alignment and Sag Vertical Curves

Sag vertical curves are a common geometric feature of tunnels. Due to the combination of limited visibility and the need for drivers to adjust their speed to account for changing longitudinal gradient, these locations have the potential to develop into bottleneck locations.

Research into the effect of sag vertical curves in tunnels was conducted by Okamura et al. (1999)[24]. They estimated the capacity, or throughput, at 19 expressway tunnel bottlenecks, including eight at sags and eleven at tunnel entrances (Table 3). This revealed that there was a significant loss of throughput if the bottleneck in the tunnel was allowed to form. For example, at a three lane tunnel with an active bottleneck, throughput dropped from 5420 to 4770 veh/h, ie 650 veh/h (12 per cent loss).
Table 3: Summary of traffic volume at tunnel bottlenecks

<table>
<thead>
<tr>
<th>Number of lanes</th>
<th>Maximum traffic volume (veh/h)</th>
<th>Traffic volume just before congestion (veh/h)</th>
<th>Traffic volume during congestion (veh/h)</th>
<th>Decrease in traffic volume (veh/h)</th>
<th>Number of bottlenecks</th>
<th>Number of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1352</td>
<td>1140</td>
<td>960</td>
<td>180</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>3620</td>
<td>3120</td>
<td>2770</td>
<td>850</td>
<td>12</td>
<td>456</td>
</tr>
<tr>
<td>3</td>
<td>5420</td>
<td>5420</td>
<td>4770</td>
<td>650</td>
<td>6</td>
<td>240</td>
</tr>
</tbody>
</table>

Source: From Okamura et al.[24].

Okamura et al.[24] considered the relationship between longitudinal gradient difference and the traffic volume before congestion (refer to Figure 14). Evidence indicated that the relationship was significant for two-lane tunnels but not for three-lane tunnels. This issue should be considered in two-lane tunnels and wider tunnels during times of two-lane traffic operation plans, whether the plan is being implemented for traffic operations purposes or maintenance activities.

Figure 14: Relationship between longitudinal gradient difference and the traffic volume before congestion

Source: From Okamura et al.[24].

Okamura et al.[24] also examined the relationship between the percentage of heavy vehicles (vehicles greater than 5.5 metres in length) and the traffic volume immediately before congestion (refer to Figure 15). Analysis revealed that the effect of increasing the proportion of heavy vehicles did not have a pronounced effect. However, there appeared to be some differences for sags in two-lane tunnels.
Figure 15: Relationship between the percentage of heavy vehicles and the traffic volume before congestion

Source: From Okamura et al[24].

A Japanese study (Yoshizawa et al.[25] testing driver behaviour, using a driver simulator with 37 participants, revealed the longitudinal change in average driving speed of all participants for gentle and sharp sag curve sections. In the experiment, the expressway appeared relatively congested to the participants and the drivers followed a lead vehicle endeavouring to maintain a separation of 70 metres when travelling at 90 km/h. The study concluded that measures to prevent queue formation at the sag would be effective in preventing traffic flow breakdown and mitigating traffic congestion.

8 Spacing of smart motorway elements in tunnels

This section provides an overview of the reasoning behind the spacing of variable speed limits/lane control signals (VSL/LCS) and tunnel message signs (TMS) within tunnels. It is based on available guidance from Austroads and Australian Standards.

8.1 Longitudinal spacing of VSL/LCS and TMS in tunnels

Section 4.3.2 noted that the spacing and placement of VSL/LCS should consider:

- The need to manage tunnel closures and incidents
- The viewing distance and legibility requirements of VSL/LCS to maximise motorists’ views of a downstream signal array
- Where alternating VSL/LCS and TMS are provided, the spacing for the element with a shorter viewing distance should determine the spacing of both elements, to avoid co-location issues and to provide a consistent driving environment.

These considerations were used to support a 120 metres longitudinal spacing of VSL/LCS and TMS in tunnels, as discussed in Sections 3.6.2 and 4.3.2.
8.2 Managing tunnel closures and incidents

As noted in Section 2.2.2.1, the design of smart motorway elements in tunnels should consider operational requirements for emergency and incident management. One method that may be applied to provide support is by aligning the location of VSL/LCS within a tunnel’s cross-passages (refer to Figure 8). Tunnel cross-connecting passages are provided for pedestrian evacuation of a tunnel and are typically provided at 120 m longitudinal spacing in tunnels.

Placing VSL/LCS at the location of cross-passages will align the management of VSL/LCS and the closure and stopping points of any lanes within the tunnel with the critical life-saving function provided by the cross-passage emergency evacuation route.

8.3 Viewing distance and legibility requirements

8.3.1 Determining legibility of TMS and VSL/LCS

There are two distances associated with the legibility of TMS and VSL that need to be considered when determining the spacing of devices in tunnels:

- Viewing distance – which is based on the height of characters used on signs and represents the maximum distance that a driver may view a sign (where sight distance is not obstructed)
- Legibility distance – which represents the distance needed for a driver to read and understand a message.
- It is desirable for the legibility distance to be less than the viewing distance. This allows for a driver to read and understand a message within the length of road that the sign may be viewed.

8.3.2 Viewing distance

The viewing distance may be determined using Equation 1. The legibility indices applicable to Equation 1 may be determined by:

- Applying the legibility indices provided in AS 1742.1-2014[26] based on the lettering series specified in AS 1744-1975[27]
- Part 10 of the Austroads Guide to Traffic Management[12] recommends VMS are made to represent upper case Series E, suggesting a legibility index of 0.65
- AS 1743-2001[20] specifies Series D narrow (DN) lettering for R4-1 speed signs, i.e. suggesting a legibility index of 0.6 for VSL.

\[ L_v = LI \times H_c \]  

Where

\( L_v \) = Viewing distance (m)  
\( LI \) = Legibility index, metres of distance per millimetre of letter height (m/mm)  
\( H_c \) = Character height (mm)
8.3.3 Legibility distance for an overhead sign

Legibility distance may be determined using Equation 2, which is taken from Section 4.3.7 Part 10 of the Austroads Guide to Traffic Management[12]:

\[ L_o = 0.105NV + 17.1S \]

Where

\[ L_o \quad = \quad \text{Legibility distance for an overhead sign} \]
\[ N \quad = \quad \text{Number of words on the sign (for 2 to 5 words)} \]
\[ V \quad = \quad \text{Travel speed of vehicles approaching sign (km/h)} \]
\[ S \quad = \quad \text{Vertical displacement of the centre above the driver eye height, for overhead mounted signs} \]

8.3.4 Application to TMS

Applying Equations 1 and 2 to a TMS would result in the following.

**Viewing distance**

Applying Equation 1: using the TMS character height and a legibility index for Series E letters (0.65):

- A 200 millimetres character height results in a viewing distance of 130 metres.

The viewing distance would represent the maximum distance that a motorist could view a downstream sign. This assumes that there are no obstructions to the downstream line of sight (e.g., horizontal or vertical curvature) that would restrict the view of the sign.

The maximum spacing could be increased by using a greater TMS character height.

**Legibility distance for an overhead sign**

Applying Equation 2, the legibility distance can be determined using the following assumptions:

\[ N \quad = \quad \text{Assumed to be 5 words} \]
\[ V \quad = \quad \text{Assumed to be 90 km/h} \]
\[ S \quad = \quad \text{Based on the following assumptions:} \quad \text{Driver eye height} = 1.15 \text{ m} \]
\[ \text{Vertical clearance to bottom of TMS} = 4.8 \text{ m} \]
\[ \text{Distance from edge to centre of TMS (125 mm), assumes 25 mm of spacing between edge of character and edge of sign} \]
\[ S = 4.8 \text{ m} - 1.15 \text{ m} + 0.125 \text{ m} = 3.775 \text{ m} \]

Based on these assumptions, the legibility distance is 111.8 metres.
This value is less than the viewing distance (130 m). This indicates that a driver has sufficient time to read and understand a TMS message within the distance that they are able to view the sign.

Testing the sensitivity of these assumptions, if a greater vertical clearance of 6.0 m was applied, the legibility distance would be 132.3 metres. This slightly exceeds the viewing distance (130 metres). In this situation, a TMS with a greater character height may be considered to increase the viewing distance and allow a driver to react to a TMS within the viewing distance.

For tunnels with a vertical clearance of greater than 5.8 metres, a TMS with a character height of greater than 200 millimetres would be required so that the legibility distance is less than the viewing distance.

8.3.5 Application to VSL/LCS

Applying Equations 1 and 2 to VSL/LCS would result in the following.

Viewing distance

Applying Equation 1: based on a VSL with a character height of 240 millimetres and a legibility index for Series D letters (0.6) would result in a viewing distance of 144 metres.

For LCS only displays, applying the 0.6 legibility index would result in viewing distances of:

- 120 metres for a LCS with a 200 millimetres character height
- 180 metres for a LCS with a 300 millimetres character height.

For a VSL/LCS, the lane control signal would be bigger than the speed limit display. It is therefore expected that the speed limit display would control the viewing distance of the VSL/LCS.

Legibility distance for an overhead sign

Applying Equation 2, the legibility distance was determined using the following assumptions:

\[
N = \text{Number of words on the sign, one word for speed limit numerals}
\]
\[
V = \text{Assumed to be 90 km/h}
\]
\[
S = \text{Based on the following assumptions:}
\]
\[
\text{Driver eye height} = 1.15 \text{ m}
\]
\[
\text{Vertical clearance to bottom of VSL/LCS} = 4.8 \text{ m}
\]
\[
\text{Distance from edge to centre of VSL/LCS} = 0.36 \text{ m}
\]
\[
S = 4.8 \text{ m} - 1.15 \text{ m} + 0.36 \text{ m} = 4.01 \text{ m}
\]

Based on these assumptions, the legibility distance is equal to 78.0 metres. This value is less than the viewing distance (144 metres). Sufficient distance is therefore provided for drivers to read and understand the message within the viewing distance, assuming there are no sight line restrictions.
Testing the sensitivity, if the vertical clearance was increased to 6.0 m, the legibility distance would increase to 98.5 metres, which remains less than the viewing distance (144 metres).

If the VSL/LCS spacing needs to be reduced for consistency with the spacing of TMS (eg 130 metres spacing), the legibility distance for the VSL/LCS (78.0-98.5 metres) remains less than the reduced spacing.

### 8.3.6 Viewing angle

Another factor that should be considered when determining the spacing of VSL/LCS and TMS is the viewing angle of an overhead mounted device. Austroads[12] suggests that the normal range of vision for overhead mounted signs should be limited to 5° vertically.

Based on this principle, as a motorist approaches an overhead mounted sign, there is a distance upstream of a sign at which a driver will be unable to view the sign. This distance may be determined as shown in Equation 3.

\[
L = S \times \cot \theta
\]

where
- \(L\) = Lateral distance upstream of an overhead sign for which a driver will be unable to view a sign within their normal range of vision
- \(S\) = Vertical displacement of the centre above the driver eye height, for overhead mounted signs
- \(\theta\) = Vertical angle corresponding with normal range of vision, suggested as 5°.

Source: Austroads[12], Section 4.3.7.

Applying Equation 3 to VSL/LCS in a tunnel with a 4.6 metres vertical clearance would result in the following.

- Based on the following assumptions:
  - Driver eye height = 1.15 m
  - Vertical clearance to bottom of VSL/LCS = 4.6 m
  - Distance from edge to centre of VSL/LCS = 0.36 m
- \(S = 4.8 \text{ m} - 1.15 \text{ m} + 0.36 \text{ m} = 3.81 \text{ m}\)
- \(\theta = 5^\circ\)

This would result in a value of distance at which a VSL/LCS would not be visible of 43.5 metres. This example is shown in Figure 16. As shown in the example, if VSL/LCS are spaced longitudinally 120 metres apart and have a viewing distance of 144 metres, there would be a distance of 19.5 metres over which:

- A driver would be upstream of VSL/LCS 1 in the diagram but would not be able to see the sign due to the viewing angle
- A driver would miss the viewing distance to VSL/LCS 2 and be unable to see a downstream sign.
Providing a VSL/LCS spacing of 120 metres that is less than the viewing distance of 144 metres helps to maximise the distance over which VSL are visible within the tunnel.

Figure 16: Effect of viewing angle
## Glossary

<table>
<thead>
<tr>
<th>Term / sign</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AID</td>
<td>Automatic Incident Detection.</td>
</tr>
<tr>
<td>AS</td>
<td>Australian Standard</td>
</tr>
<tr>
<td>AGRT</td>
<td>Austroads Guide to Road Tunnels.</td>
</tr>
<tr>
<td>AVID</td>
<td>Automatic Video Incident Detection.</td>
</tr>
<tr>
<td>CCTV</td>
<td>Closed Circuit Television – uses video cameras to transmit a signal to the motorway control centres where operators monitor traffic conditions and incidents. A separate system of web cameras is used to display images on the Roads and Maritime Livetraffic Website.</td>
</tr>
<tr>
<td>Element</td>
<td>Technology or other design feature that delivers a smart motorway function</td>
</tr>
<tr>
<td>Emergency telephone</td>
<td>A roadside telephone providing road users with a method of directly contacting an operator/designated responder to facilitate assistance</td>
</tr>
<tr>
<td>ESB</td>
<td>Emergency Stopping Bay. A space provided to store vehicles clear of trafficable lanes</td>
</tr>
<tr>
<td>ESL</td>
<td>Emergency Shoulder Lane. Also referred to as hard shoulder</td>
</tr>
<tr>
<td>Full coverage</td>
<td>Where CCTV provides 100 per cent coverage of the carriageway including the mainline, interchanges, emergency stopping lanes and emergency stopping/maintenance bays, emergency telephones, bridges and other structures, arterial and intersecting routes.</td>
</tr>
<tr>
<td>HSR</td>
<td>Hard Shoulder Running</td>
</tr>
<tr>
<td>Intersecting roads</td>
<td>Roads intersecting any motorway entry ramps or exit ramps.</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transport System</td>
</tr>
<tr>
<td>LCS</td>
<td>Lane Control Signal</td>
</tr>
<tr>
<td>Long underpass</td>
<td>Motor vehicle underpass which has a continuous roof structure equal to or greater than 60m and less than 120m in length.</td>
</tr>
<tr>
<td>Low-clearance structure</td>
<td>A roadway structure with a clearance of less than 4.6 metres.</td>
</tr>
<tr>
<td>LUMS</td>
<td>Lane Use Management System</td>
</tr>
<tr>
<td>NSW</td>
<td>New South Wales</td>
</tr>
<tr>
<td>Operations management and control system (OMCS)</td>
<td>Integrated control system for all motorway control, monitoring and communication systems required for traffic and incident management on the motorway network including approach roads and ramps. Includes monitoring and control of motorway plant and equipment. A tunnel OMCS may also include tunnel specific traffic safety and environmental management systems such as those required for drainage, fire safety, ventilation, air quality, noise, lighting, radio re-broadcast and public address.</td>
</tr>
<tr>
<td>Over-height vehicle</td>
<td>In NSW, a vehicle is defined as over-height if its height exceeds 4.3 metres.</td>
</tr>
<tr>
<td>Overlapping coverage</td>
<td>Where CCTV provides 200 per cent coverage and 100 per cent redundancy, ie where more than one camera can view the same location.</td>
</tr>
<tr>
<td>Term / sign</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>PTZ camera</td>
<td>Camera with ‘pan, tilt and zoom’ functionality</td>
</tr>
<tr>
<td>RMS</td>
<td>Roads and Maritime Services</td>
</tr>
<tr>
<td>SCATS</td>
<td>Sydney Coordinated Adaptive Traffic System</td>
</tr>
<tr>
<td>Short underpass</td>
<td>Motor vehicle underpass which has a continuous roof structure less than 60 m in length.</td>
</tr>
<tr>
<td>Smart motorway</td>
<td>A motorway that utilises complementary technologies to create a fully managed road environment that maximises the performance of the existing road infrastructure. Previously referred to as managed motorway or smart managed motorway.</td>
</tr>
<tr>
<td>Stopping points</td>
<td>Points upstream or at a tunnel portal with traffic control measures to implement a carriageway closure and stop traffic from advancing beyond that point.</td>
</tr>
<tr>
<td>TMS</td>
<td>Tunnel Message Sign, smaller sized VMS that are provided in tunnels.</td>
</tr>
<tr>
<td>Tunnel</td>
<td>A motor vehicle underpass which has a continuous length structure equal to or greater than 120 m in length, measured parallel to the road alignment. For the purpose of this design guide only, the term ‘tunnel’ is also used to include long underpasses which are underpasses with a continuous roof structure equal to or greater than 60m and less than 120 m in length.</td>
</tr>
<tr>
<td>Tunnel portal</td>
<td>The entrance to a tunnel where entry must be controlled. Also applies to exits.</td>
</tr>
<tr>
<td>VMS</td>
<td>Variable Message Sign</td>
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<tr>
<td>VSL</td>
<td>Variable Speed Limit</td>
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<tr>
<td>VSL/LCS</td>
<td>An overhead lane use device incorporating a LCS and VSL sign.</td>
</tr>
<tr>
<td>Warrant</td>
<td>Criteria or threshold guiding application of a smart motorway element to a section of the NSW motorway network. If a warrant is met in a particular case, then further investigation is still required to determine if it is appropriate for the smart motorway element to be applied to a specific motorway section, considering other matters relevant to smart motorway design and operation. If a warrant is not met in a particular case, it is highly likely that the smart motorway element would not be required on that motorway section.</td>
</tr>
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</table>
10 References

The resources shown in Table 4 are directly referenced in this design guideline. Some of these sources may have limited access for non-subscribers.

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<th>Author</th>
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<tr>
<td>[6]</td>
<td>AS 4428.4 Fire detection, warning, control and intercom systems – Control and Indicating Equipment</td>
<td>2004</td>
<td>Standards Australia</td>
<td>Online</td>
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<td>[7]</td>
<td>AS 1670.4 Fire detection, warning, control and intercom systems - System design, installation and commissioning</td>
<td>2004</td>
<td>Standards Australia</td>
<td>Online</td>
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<td>[8]</td>
<td>AS 60849 Sound systems for emergency purposes</td>
<td>2004</td>
<td>Standards Australia</td>
<td>Online</td>
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<td>[16]</td>
<td>Static and Active Signposting to Divert Overheight Vehicles Around Low Clearance Structures - Best Practice Methodologies</td>
<td>2013</td>
<td>ARRB Group</td>
<td>Roads and Maritime</td>
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<td>[18]</td>
<td>Smart Motorway Supplement for Lane Use Management Systems including Variable Speed Limits</td>
<td>2016</td>
<td>Roads and Maritime</td>
<td>Roads and Maritime</td>
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<td>[22]</td>
<td>Influence of the Fixation Point on Tunnel Entrance Lighting</td>
<td>1973</td>
<td>Narisada, K &amp; Yoshikawa, K</td>
<td>Online</td>
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<td>[27]</td>
<td>Standard Alphabets for Road Signs, AS 1744-1975</td>
<td>1975</td>
<td>Standards Australia</td>
<td>Online</td>
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## Document control

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## Revision history

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