Managed Freeways Provision Guidelines
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SUMMARY

Managed Freeways Policy Framework

Main Roads Western Australia (Main Roads) has established a policy framework to guide overall planning, project development, delivery and ongoing operation of Managed Freeways in Western Australia (WA). The Policy Framework includes the documents listed in the table below, and this document consists of the Managed Freeways Provision Guidelines.

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Using the VicRoads’ Managed Freeway Guidelines (2010a) as a basis, these guidelines have been developed in consultation with key stakeholders and reference policy and technical documentation from Main Roads, other state road authorities and Austroads.

Managed Freeways Concept

Managed Freeways make the best use of the existing freeway network, particularly during times of high demand and traffic incidents. This is realised through the application of intelligent transport systems (ITS) and operation strategies that enable dynamic network management and operation in real-time. Managed Freeways interventions, complemented with appropriate mainline and ramp geometric improvements, work together as an integrated system to achieve and maintain optimal freeway traffic conditions, with minimal delays and congestion.

Managed Freeways design should consider the road user and road manager perspective:

- **Road user** – the Managed Freeway provides an enhanced driving experience and meets the road user’s expectations for safe and reliable travel on a preferred traffic route.
- **Road manager** – the Managed Freeway meets the road manager’s need for the most efficient and productive use of existing freeways through real-time monitoring and control of traffic.

Traffic Flow Theory

An understanding of contemporary traffic flow theory is critical for the design of Managed Freeways. Traffic data from WA’s existing freeways exhibits similar characteristics of flow breakdown and capacity loss to that demonstrated by research on other freeways in Australia / internationally.

On the Mitchell Freeway, a typical occurrence of flow breakdown can result in a 60 km/h drop in speed and decrease in flow from 2,100 veh/h/lane to 1,450 veh/h/lane during the PM peak period.
This means that a four-lane freeway is delivering the throughput of a three-lane freeway (approximately 6,000 veh/h) and effectively a lane of freeway capacity has been lost.

A consistent approach to Managed Freeways design can be applied across urban freeways as the principles of flow breakdown and capacity loss are universal. Flow breakdown is probabilistic, and data from Perth’s freeways indicates that there is a 10% likelihood of flow breakdown once peak flows of 1,700 veh/h/lane are achieved. This aligns with findings from international research and provides the context for the MF warrants.

Recent traffic flow research, supported by field observations from current Managed Freeways projects, indicates that improved capacity at merge areas that is sustained despite increasing demand can be effectively achieved by managing the critical density (occupancy)\(^1\) on the mainline with coordinated ramp signals. Coordinated ramp signals can prevent the occurrence of flow breakdown and congestion, whilst also work to restore traffic flow faster in case of flow breakdown due to an incident.

**Design Guidance and Interventions Warrants**

Managed Freeways project development and design should begin with traffic analysis to identify current (and future) locations and causes of recurrent flow breakdown and congestion, as well any safety issues, on a section of freeway. This will inform the application of the ‘toolkit’ of ITS and technology-based interventions.

Interventions can be categorised in terms of the following functions:

- **Control** – of freeway access, lane use and speed to provide capacity improvements and support incident, event and congestion management. Interventions include ramp signalling, lane use management systems (for dynamic use of the full pavement), variable speed limits and priority vehicle facilities.
- **Traveller information** – to enable road users to make informed route choices and improve safety during incidents. Interventions include freeway and arterial road variable message signs.
- **Network intelligence** – to the freeway control system and road manager, by providing traffic and network data to support the operation of control and traveller information interventions. Interventions include vehicle detectors, CCTV and travel-time calculations.

The interventions should be considered for deployment at two levels dependent on the traffic volumes of the section of freeway and the occurrence of flow breakdown and congestion. The two levels are foundation level of ITS and Managed Freeways.

**Foundation Level of ITS**

Main Roads’ policy is that all freeways will, as a minimum, have real-time network intelligence and monitoring capabilities, and provision for higher order MF interventions when needed. This means that all current and future projects on the existing and planned freeway network should incorporate a foundation level of ITS, which also includes provision of roadside traveller information and consideration of ramp layouts to facilitate future retrofitting of ramp signals.

**Requirements for a foundation level of ITS** apply to all lightly to moderately trafficked carriageways experiencing an annual average daily traffic volume up to 15,000 veh/lane (based on current volumes). Appendix A provides a summary of requirements for specific interventions.

---

\(^1\) The critical occupancy (a surrogate for density in control systems as it is easier to measure) at which capacity flow occurs is used to manage freeway flow, as unlike capacity it is found to be fairly stable even under adverse weather conditions. The occupancy measurement is considered to be the most appropriate parameter for optimising throughput, rather than speed or flow rate.
**Managed Freeways**

For the purpose of this document, a Managed Freeway is a freeway comprising well-designed infrastructure and where out of the higher order ITS interventions (i.e. above foundation-level ITS) at least coordinated ramp signals have been applied as appropriate in order to achieve Main Roads’ objectives for optimal freeway performance. Additional interventions may also be applied as appropriate.

**Managed Freeways** requirements apply to all moderately to heavily trafficked carriageways experiencing an annual average daily traffic volume of 15,000 veh/lane or more (based on current volumes), as there is the likelihood that flow breakdown may occur once these volumes are reached.

Managed Freeways should also be considered on sections of freeway where flow breakdown and congestion already occurs on a recurrent basis (i.e. due to oversaturation) at values lower than this threshold, as determined by freeway traffic analysis. An indicator of recurrent congestion is when average peak period travel speeds are approximately 60% or less of the posted speed limit.

Appendix B provides a summary of requirements for specific interventions.

General guidance on Managed Freeways design and priorities for deployment of ITS interventions on freeways is as follows:

- Where possible, all critical mainline bottlenecks causing recurrent congestion should be ameliorated through suitable geometric design improvement options.

- Minor geometric mainline improvements and ramp modifications (i.e. civil upgrades) should first be investigated to help improve the operational efficiency of the freeway. For example, provision of additional lanes at localised lane drops, increase in exit ramp storage and entry ramp length and auxiliary lanes. Existing design strategies for lane markings and fixed signing should also be reviewed.

- If localised geometric improvements are practically, economically or politically unfeasible, or if traffic modelling still indicates that recurrent flow breakdown and congestion will occur after minor civil upgrades have been undertaken, then ITS and technology-based control interventions should be investigated alongside mainline widening options.

- The warrants for deployment of control interventions to achieve capacity improvements are detailed below.

  Note: The warrants should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes. The control interventions should be applied to a freeway route where the warrant is met at a critical bottleneck for the route i.e. the warrant may not have to be met across the entire section of the route for the intervention to be applied. In many cases, a route treatment may be necessary to prevent flow breakdown at the critical bottleneck.

  - **Peak period traffic flow rate ≥ 1,800 pc/h/lane (approx. 1,700 veh/h/lane with 10% heavy vehicles)** — consider deployment of coordinated ramp signalling (CRS), including freeway-to-freeway ramp signalling, as a route-based treatment. CRS provides system control to restore and sustain existing capacity.

  - **Peak period traffic flow rate ≥ 2,000 pc/h/lane (approx. 1,900 veh/h/lane with 10% heavy vehicles)** — consider deployment of variable speed limits (VSL) as a route-based treatment. VSL can support CRS in sustaining existing capacity.

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2 Passenger car equivalent values (pc/h/lane) are used instead of veh/h/lane values to account for the presence of heavy vehicles. A heavy vehicle equivalency factor of 1.5 (for level terrain) has been used however factors of 2.5 and 4.5 are applicable for rolling terrain and mountainous terrain respectively.
— **Peak period traffic flow rate ≥ 2,200 pc/h/lane (approx. 2,100 veh/h/lane with 10% heavy vehicles)** — consider deployment of lane use management systems (LUMS), integrated with VSL\(^3\), to implement all lane running or part-time emergency lane running operational strategies. These options should be compared with mainline widening solutions.

LUMS enable dynamic utilisation of the full pavement asset on a full- or part-time basis, providing additional ‘physical’ capacity when required. Benefit-cost analysis and whole-of-life-cycle costing should be undertaken to compare ITS treatments with civil upgrade options to determine the best approach. This warrant is only likely to apply to freeways with CRS since unmanaged freeways are unlikely to sustain these flow rates.

- Isolated ramp signals may be utilised to address localised capacity and control issues. LUMS integrated with VSL can be deployed as appropriate specifically to facilitate incident and event management, particularly on sections where there are high rates of speed-related incidents. VSL can also provide queue protection.
- Managed Freeways should incorporate an enhanced level of roadside traveller information. Freeway and arterial road variable message signs play an important part in managing traffic through display of real-time travel-time and freeway condition information to influence route choice and improve safety during incidents.
- A Managed Freeway section will also require an enhanced level of provision of network intelligence interventions, such as vehicle detectors and CCTV, to support the operation of the control and traveller information interventions.

A successful Managed Freeways project may require a combination of geometric improvements / civil upgrades and ITS and technology interventions. The design life assessment for Managed Freeways projects must take into account that there are different design life assumptions for ITS and technology interventions to traditional civil works. The impact of peak hour spreading on design volumes should also be considered.

\(^3\) Also, in practice where VSL is implemented via overhead mounting (e.g. for carriageways with four or more lanes and / or a traffic mix of 7% or more of heavy vehicles), it is likely to be integrated with LUMS therefore on some occasions LUMS may be implemented at 1,900 veh/h/lane as well.
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INTRODUCTION

1.1 Managed Freeways Policy Framework

Main Roads Western Australia (Main Roads) has established a policy framework to guide implementation and operation of Managed Freeways (MF) in Western Australia (WA). Table 1.1 provides a description of each document within the policy framework. This document forms the MF Provision Guidelines.

Table 1.1: Managed Freeways policy framework documentation

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1.2 Purpose of Document

This document outlines Main Roads’ provision guidelines for deployment of MF on the existing and future freeway network in WA. The document covers the following key topics:

- background on the MF concept (Section 2)
- introduction to contemporary traffic flow theory and implications for MF design (Section 3)
- high-level guidance on the approach to MF design, covering freeway traffic analysis, design-life assumptions, overview of ITS and technology interventions in the MF ‘toolkit’ and priorities for application (Section 4)
- detailed provision guidelines for each intervention, including description and purpose, warrants and application guidelines, and technology and installation configurations (Sections 5, 6 and 7)
- description of foundation infrastructure required to support MF (Section 8).

1.3 Acknowledgement

The VicRoads Managed Freeway Guidelines (2010a) has been used as the basis for development of this document. Additional policy and technical documentation from Main Roads, other state road authorities and Austroads was also referenced. Consultation was undertaken with key stakeholders across Main Roads, including the following branches:

- Road Network Operation Management, Road Network Services
- Traffic Operation and Services, Road Network Services
- Heavy Vehicle Operations, Road Network Services
- Road and Traffic Engineering, Planning and Technical Services
- Road Planning, Planning and Technical Services
- Major Projects, Infrastructure Delivery.
2 MANAGED FREEWAYS CONCEPT

Managed Freeways make the best use of the existing freeway network, particularly during times of high demand and traffic incidents. This is realised through the application of intelligent transport systems (ITS) and operation strategies that enable dynamic network management and operation in real-time. MF interventions, complemented with appropriate mainline and ramp geometric improvements, work together as an integrated system to achieve and maintain optimal freeway traffic conditions, with minimal delays and congestion.

An actively managed freeway incorporates a number of interventions that collect network intelligence and monitor freeway performance, control and manage the traffic flow, and inform road users in real-time.

MF design should consider both the road user and road manager perspectives, as described in Table 2.1.

### Table 2.1: Road user and road manager perspectives of Managed Freeways

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<td>The managed freeway provides an enhanced driving experience and meets the road user’s expectations for safe and reliable travel on a preferred traffic route.</td>
<td>The managed freeway meets the road manager’s need for the most efficient and productive use of existing freeways through real time monitoring and control of traffic.</td>
</tr>
<tr>
<td>▪ Safe travel environment through speed limits that reflect real-time road conditions.</td>
<td>▪ Real-time and reliable data on traffic and network conditions to assist traffic control and provision of traveller information.</td>
</tr>
<tr>
<td>▪ Travel at satisfactory, but not necessarily free-flow speeds, throughout the day.</td>
<td>▪ Minimisation of flow breakdown and optimisation of freeway capacity through optimal management of the traffic flow.</td>
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<tr>
<td>▪ Reliable travel-time, with only a small buffer required in trip planning.</td>
<td>▪ Rapid restoration of traffic flow in the event of a flow breakdown due to an incident.</td>
</tr>
<tr>
<td>▪ Timely and advanced warning of freeway conditions and disruptions, in order to make appropriate decisions on alternative routes and / or modes.</td>
<td>▪ Real time control on freeway access, lane use and speed limits, in response to changing travel conditions.</td>
</tr>
<tr>
<td>▪ Once on the freeway, near real-time information of downstream freeway conditions, disruptions and hazards, and advice on appropriate actions to be taken.</td>
<td>▪ Influence en route choice, in response to changing travel conditions or to assist priority for users.</td>
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<tr>
<td>▪ Consistent and clear instructions on mandatory lane closures and variable speed limits.</td>
<td>▪ Effective management of congestion and incidents, including quick clearance, through reliable and prompt detection and verification of incidents and disruptions as well as timely provision of traveller information.</td>
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<tr>
<td>▪ Enhanced driver experience.</td>
<td>▪ User-friendly control system and user interface for easy and effective operation of all ITS interventions on the network.</td>
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Source: Adapted from VicRoads (2010a)
Main Roads’ *Managed Freeways Policy Discussion Paper* (ARRB 2012a) highlights that not every section of an MF needs to include all of the interventions available within the ‘toolkit’. Interventions should be applied as appropriate to address a particular issue on the network or provide an identified user service, although they are generally most effective when used in combination. There are some interventions that are critical to effective operation of MF, whereas others may be considered as optional as they provide an enhanced level of service or address problems at very specific locations on the network.

The following series of graphics show how the interventions of the MF toolkit and their combined use of network intelligence, traffic control and traveller information contributes to a fully managed freeway environment. The series of images do not relate to the same situation, but illustrate a range of capabilities of the interventions.

Note: These images reflect the Victorian perspective and are for illustrative purposes only. Implementation in WA may be different and when appropriate graphics have been developed and approved these will be incorporated to this document as part of a subsequent revision.

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*Coordinated ramp signals on the entry ramps of the freeway control the access to the freeway to minimise the risk of congestion due to flow breakdown. Vehicle detectors enable adaptive operation of the ramp signals and closed circuit television (CCTV) cameras allow monitoring of traffic conditions.*

![Coordinated ramp signals on the entry ramps of the freeway](source-image)

*Source: VicRoads (2010a).*

*Figure 2-1: Coordinated ramp signals on the entry ramps of the freeway*
Integrated speed and lane use management assists safe operation of the freeway during incidents and can be used to increase capacity by enabling full pavement utilisation (i.e. no emergency lane) on a full-time or part-time basis.

Figure 2-2: Integrated speed and lane use management system on the freeway

On approach to the freeway, the road user is able to make informed decisions about route choice.

Figure 2-3: Real-time travel-time information displayed on variable message signs on the approach to the freeway

VMS on the freeway provide information to road users. In the figure below the signs show information on the reason for reduced speed limits and the action required (merge right).


Figure 2-4: VMS on the freeway displaying incident information

In addition to the on-road environment, another key element of MF is a comprehensive traffic operations centre, where traffic operators undertake ongoing network surveillance and incident management. Ongoing operations are also supported by systems engineers that undertake system performance tuning (optimisation) and fault management.

Figure 2-5: Traffic operators dynamically monitoring the network in real-time
3 MANAGED FREEWAYS TRAFFIC FLOW THEORY

The following section provides an overview of key principles of traffic flow theory informing traffic flow analysis and MF design. The summary is largely based on the VicRoads’ Managed Freeways: Freeway Ramp Signals Handbook (2010b) and the ‘Discussion Paper on Freeway Mainline Capacity at Entry Ramp Merges’ produced by ARRB for Main Roads (ARRB 2012b). Refer to these sources for further detail.

3.1 Impact of Flow Breakdown on an Unmanaged Freeway

Traffic flow breakdown is the condition where free-flowing traffic experiences a significant and sudden reduction in speed, with a sustained loss in throughput. Just prior to flow breakdown the flow exceeds capacity. This occurs for a range of factors when high mainline flows are not sustainable and can happen at any location on a freeway regardless of the design standard.

Bottlenecks are fixed locations where the capacity is lower than the upstream capacity, and critical bottlenecks are those locations where flow breakdown usually occurs first, for example where there is merging traffic from an entry ramp or at a lane drop. Resulting congestion may be localised near the bottleneck or more usually it will create a moving queue with a shockwave that travels upstream to affect the performance over an extended section of freeway.

Figure 3-1 illustrates the impact of flow breakdown in an unmanaged freeway. This example of the Mitchell Freeway in the vicinity of the Vincent Street interchange demonstrates a 60 km/h drop in speed and decrease in flow from 2,100 veh/h/lane to 1,450 veh/h/lane during the PM peak period. The four-lane freeway is delivering the throughput of a three-lane freeway (approximately 6,000 veh/h), in other words, a lane of freeway capacity has been lost. This low performance lasted for the duration of the peak period, when high demand means that the freeway is needed to perform at maximum capacity. Maximum flow is only achieved when traffic density is at an optimum value and flow breakdown occurs when density rises above this optimum value (ARRB 2012b). Further, more, the effects of congestion are felt for a much greater distance along the freeway due to the shockwave phenomenon.

Further illustration of the performance of unmanaged freeways in WA during congested periods on typical weekdays in 2012 is provided in Figure 3-2 and Figure 3-3.

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4 Main Roads has developed a Supplement (2012c) to VicRoads’ Managed Freeways – Freeway Ramp Signals Handbook (2010b) which should always be referred to in conjunction with the VicRoads publication.
Source: Main Roads Western Australia 1 minute data (15 minute rolling average) for Wednesday 11 August 2010 (ARRB 2012).

Figure 3-1: Implications of traffic flow breakdown on Mitchell Freeway (at Vincent ST Interchange – four lanes); capacity and travel speed during the PM peak period

Source: Main Roads Western Australia 1 minute data (15 minute rolling average) for 6 February 2012.

Figure 3-2: Congestion bottleneck on Mitchell Freeway (southbound near Whitfords interchange); traffic volumes and average travel speed over a 24 hour period

5 The flow volumes include mainline freeway volumes and ramp volumes, at the same minute. This is because the detectors are located prior to the merge and so there are two freeway lanes and one ramp lane rather than detectors at a location with the combined flow after the merge. The two freeway lanes had a peak flow of ~1,900 veh/h/lane and with the added ramp lane it was ~2,400 veh/h/lane.
3.2 Contemporary Traffic Flow Theory

Contemporary research has sought to improve understanding about the mechanisms that lead to flow breakdown and recovery as well as traffic behaviour under congested conditions. ARRB’s research paper on ramp merge entry analysis highlights new developments and challenges to traditional traffic flow theory, and implications for MF design (ARRB 2012b).

A key understanding of contemporary theory is that traffic breakdown can occur at different flow capacity values on different days under similar environmental conditions, becoming more pronounced in adverse weather conditions. This is because freeway capacity is not deterministic but rather random or stochastic and that breakdown probability can be related to traffic flow and driver behaviour. This was demonstrated by Brilon et al. (2005, cited in ARRB 2012b) which indicates that a flow of approximately 2,100 veh/h/ lane equates to 85% probability of flow breakdown. Similar values are also evidenced in traffic data from Perth’s freeways (Figure 3-4).

There is also a growing body of research that challenges the traditional assumption outlined in the HCM evaluation methodology that merge and diverge segments have the same capacity as a similar basic freeway segment. Research by Shawky and Nakamura (2007, cited in ARRB 2012b) demonstrates that an increasing ratio of entry ramp flow to outflow rates leads to higher breakdown probability. Also, Cassidy and Rudjanakanoknad (2002, cited in ARRB 2012b) demonstrate that increasing entry ramp flows lead to lower mainline downstream capacity. Figure 3-5 illustrates how ramp volumes over a certain threshold can result in flow breakdown on the mainline, resulting in substantially reduced volumes on both the mainline and ramps.
Figure 3-4: Probability of flow breakdown on the Mitchell Freeway (southbound at Whitfords Avenue entry ramp)

Source: Main Roads Western Australia 5 minute data.6

Figure 3-5: Effect of flow breakdown on mainline and ramp volumes for the Mitchell Freeway (southbound at Whitfords Avenue interchange) in the AM peak period

Source: Main Roads Western Australia 1 minute data (15 minute rolling average) for Monday 30 January 20127.

6 The graph was produced from freeway mainline data for over 400 days (spanning two years) where flow breakdown occurred at one location of a critical bottleneck on a two-lane freeway just prior to an onramp merge. It uses flow value obtained just prior to flow breakdown, where the speed typically drops from around 60-70 km/h to 30-40 km/h. Similar graphs can be produced from other locations, however this location has the most reliable data.

7 This is a representative day where flow breakdown occurred at ~1,800 veh/h/lane.
Appreciation of contemporary traffic flow theory therefore has the following important implications for MF design.

- Congested freeways require management of a system rather than treatments in isolation. The development of coordinated control systems focuses on the causes of congestion and the prevention of flow breakdown by managing traffic flow within control thresholds, rather than treating the symptoms or effects of congestion (VicRoads 2010b). Bottleneck analysis is vital to separate the cause (i.e. critical bottlenecks) from symptoms (i.e. shockwave patterns).

- Since freeway capacity at merge areas is affected by the supply of traffic at entry ramps, ramp entry merge area analysis is important. Improved capacity at merge areas that are sustained despite increasing demand can be effectively achieved by managing the critical occupancy (density) on the mainline with coordinated ramp signals, which control access and therefore supply of traffic to the freeway (ARRB 2012b).

- MF design should facilitate the development of a resilient transport system that can absorb a `shock` as well as recover to a steady state in the event of a failure. This means in addition to minimising the occurrence of flow breakdown, the system must also facilitate recovery if flow breakdown does occur, for example after an incident. This can be achieved using coordinated ramp signalling which manages supply to the mainline, as well as other approaches such as provision of traveller information.

- A key principle for coordinated ramp signal design is to prevent the occurrence of flow breakdown. Given that the traffic flows at which breakdown occurs can be highly variable, warrants for interventions should consider the flow level at which flow breakdown is likely to start occurring (i.e. flows higher than 1,500 veh/h/lane), rather than maximum flows or speeds. The latter are less effective as warrants as they are unlikely to be achieved for sufficient time to be measured during periods of high demand.

- Maximum theoretical capacities traditionally used for freeway design are rarely achieved or sustained in practice. Operational capacity values, which represent the optimal capacity flow prior to breakdown, should therefore be used for ramp entry merge analyses and design. Using the flow breakdown probability curve, an appropriate maximum capacity value for design to minimise the probability of flow breakdown may be the value where there is 10% probability of flow breakdown. This equates to 1,800 pc/h/lane and 2,100 pc/h/lane for unmanaged and managed freeways respectively (ARRB 2012b). 1,800 pc/h/lane is also considered an appropriate threshold for the first MF intervention, coordinated ramp signalling.

This section has highlighted that an understanding of contemporary traffic flow theory is critical for the design of MF. Traffic data from WA’s existing freeways exhibits similar characteristics of flow breakdown and capacity loss to that demonstrated by national and international research. A consistent approach to MF design can therefore be applied across urban freeways as the principles of flow breakdown and capacity loss are universal.

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8 The critical occupancy (a surrogate for density in control systems as it is easier to measure) at which capacity flow occurs is used to manage freeway flow, as unlike capacity it is found to be fairly stable even under adverse weather conditions. The occupancy measurement is considered to be the most appropriate parameter for optimising throughput, rather than speed or flow rate.

9 Passenger car equivalent values (pc/h/lane) are used instead of veh/h/lane values to account for presence of heavy vehicles. A heavy vehicle equivalency factor of 1.5 (for level terrain) has been used however it should be noted that factors of 2.5 and 4.5 are applicable for rolling terrain and mountainous terrain respectively.
4 APPROACH TO MANAGED FREEWAYS DESIGN

The following sections provide general guidance on the recommended approach to Managed Freeways (MF) design in WA in relation to freeway analysis, design life assumptions, peak spreading, interventions in the MF toolkit and the priorities for their application to existing and planned freeways in WA.

Note: This chapter will be reviewed at a later date to ensure alignment with the systems engineering model that is being adopted and developed by Main Roads WA to support implementation of MF. This approach focuses on ITS services and technology functional requirements.

4.1 Freeway Analysis

4.1.1 Traffic Analysis

MF interventions may not be appropriate in the first instance to address localised congestion due to bottlenecks caused by geometric constraints such as lane drops, which may be rectified through geometric improvements at relatively low cost. An analysis of the section of freeway proposed for MF should be undertaken to identify the reasons for flow breakdown including such bottlenecks, which should inform the subsequent determination of MF interventions.

Freeway traffic analysis and modelling should therefore be used to identify existing issues on the network, for example sections of the freeway where flow breakdown and congestion is currently occurring or expected to occur at the time of opening of the MF project (i.e. approx. 5 years after project inception).

Freeway traffic analysis should use validated data and include detailed bottleneck and merge analysis. It should also consider the following investigations (this list is not exhaustive):

- daily / peak period profiles of traffic flow and occupancy
- daily / peak period profiles of speed (relative to time)
- frequency and duration of flow breakdown and congestion (i.e. duration of peak periods)
- potential for and causes of recurrent flow breakdown and congestion at a specific location. For example, to identify if the data represents congestion from flow breakdown as a result of a:
  - critical bottleneck at that location
  - shockwave from critical bottleneck downstream
  - potent / latent bottleneck at that location (these bottlenecks activate when flow breakdown occurs at a result of flow exceeding capacity but after the critical bottleneck).

It is recommended that heat plots derived from vehicle detector data (refer to Figure 3-3 for an example) are used to support traffic / bottleneck analysis by helping to identify the location, duration and intensity of congestion.

This will help to identify the most appropriate interventions to address the cause of the flow breakdown and congestion across a section of freeway. For example, it will indicate whether a coordinated (route-based) ramp signal treatment is required and whether geometric improvements or dynamic full pavement utilisation should be considered to provide additional ‘physical’ capacity.

Given that ITS interventions incur operations and maintenance costs from opening, it is further recommended to assess traffic volumes against the MF warrants using a five-year forward
projection (from opening), with a sensitivity check at ten years to ensure that the design could accommodate requirements in ten years with minimal incremental cost. This will help determine whether it is better to implement ITS interventions now and avoid the extra costs of retrofitting balanced against the operation and maintenance costs of installing too early. For example, if civil upgrades are being undertaken, the capacity improvements delivered by the civil upgrades may result in a delay in meeting warrants for ITS interventions such as coordinated ramp signals. In such cases the ITS support and foundation infrastructure should still be provided during the civil upgrades and when time comes to warrant ITS interventions the foundation is already there. This should be discussed with Main Roads during the project planning and development phases.

4.1.2 Safety Analysis

MF interventions can also provide significant safety benefits and may be used to address safety issues, for example locations where high accident rates are experienced.

Safety analysis should be undertaken to determine various characteristics of incidents that occur on a section of freeway, such as the type (i.e. congestion or speed-related), severity and time-of-day of occurrence. This will help identify if preventative measures are appropriate, for example to minimise the occurrence of congestion through coordinated ramp signalling. It will also help determine whether interventions such as lane use management systems and variable speed limits will be effective in managing the incident after it has occurred. For example, by minimising the occurrence of secondary incidents by diverting traffic safely around the incident and reducing speeds to provide queue protection and reduce the risk to incident responders.

4.2 Toolkit of Interventions for MF

The 'toolkit' of interventions should be used to support Main Roads in meeting its commitment to provide the most productive and resilient freeway network capable of delivering the maximum travel reliability, efficiency, safety and sustainability benefits to the community. In line with Main Roads' objectives, MF must also provide an enhanced driver experience and develop 'smart' roads in preparation for future cooperative ITS (ARRB 2012a and Main Roads 2012a).

There are a range of interventions that can be used to achieve Main Roads' objectives for the WA freeway network. These can be considered in terms of three key ITS service or functional categories: control, traveller information and network intelligence. The deployment of ITS interventions on a section of freeway must also be supported by the provision of foundation infrastructure.

The following sub-sections provide a brief description of each category and associated interventions, with further details provided in Sections 5, 6, 7 and 8.

4.2.1 Control Interventions

ITS providing real-time traffic control are the key interventions that deliver capacity improvements to prevent or delay the occurrence of flow breakdown and congestion, particularly during peak times and incidents. Traffic control includes control of vehicle access to the freeway as well as speed and lane use of vehicles on the mainline.

Capacity improvements are achieved by:

- ensuring the full operational capacity of the freeway is utilised at all times, including periods of high demand, through the use of coordinated ramp signals (and possibly supported by variable speed limits)
- providing additional 'physical' capacity as required i.e. full pavement utilisation, including the emergency lane, on a full-time or part-time basis and dynamic allocation of available road space through lane use management systems.
The reduction in flow breakdown and congestion results in both traffic flow and safety benefits.

The control systems also assist with the safe management of traffic during congestion, incidents and events. They can facilitate recovery to optimal traffic conditions when flow breakdown has occurred and minimise the occurrence of secondary incidents. Access and lane control can also be used to provide priority facilities and minimise delay for high-value road users.

The ITS or technology-based elements that are required to deliver these functions are listed in Table 4.1.

Table 4.1: Key ITS services providing control functions

<table>
<thead>
<tr>
<th>Key ITS service (intervention)</th>
<th>ITS and technology elements</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp signalling</td>
<td>▪ freeway ramp signals</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>▪ supported by other network intelligence / traveller information elements</td>
<td></td>
</tr>
<tr>
<td>Implemented as a corridor-wide treatment, e.g. coordinated ramp signalling (CRS) including freeway-to-freeway ramp signalling, or a localised treatment, e.g. isolated ramp signalling. Provides access control to achieve: ▪ capacity improvement i.e. restore and sustain existing capacity ▪ congestion, incident and event management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable speed limits (VSL)</td>
<td>▪ variable speed limit signs(^{10})</td>
<td>5.2</td>
</tr>
<tr>
<td>Provides speed control to achieve: ▪ incident and event management (in association with lane use management) ▪ queue protection ▪ capacity improvement i.e. support CRS in sustaining existing capacity</td>
<td>▪ supported by other network intelligence / traveller information elements</td>
<td></td>
</tr>
<tr>
<td>Lane use management systems (LUMS)</td>
<td>▪ lane use management systems (LUMS)(^{11})</td>
<td>5.3</td>
</tr>
<tr>
<td>Provides lane use control (in association with speed control) to achieve: ▪ capacity improvement i.e. expand capacity through dynamic use of full pavement (includes operational strategies such as all lane running ALR), part-time emergency lane running (ELR) and reversible lanes) ▪ incident and event management</td>
<td>▪ supported by other network intelligence / traveller information elements</td>
<td></td>
</tr>
<tr>
<td>Priority vehicle facilities</td>
<td>▪ various</td>
<td>5.4</td>
</tr>
<tr>
<td>Arterial road traffic control</td>
<td>▪ arterial road traffic signals / detectors (SCATS)</td>
<td>5.5</td>
</tr>
</tbody>
</table>

\(^{10}\) In some circumstances VSL may be integrated with LUMS through combined use of overhead lane signals. Refer to Section 5.2.

\(^{11}\) LUMS usually incorporate variable speed limits through combined use of overhead lane signals, unless there are specific geometric constraints i.e. in tunnel environments.
MF design should also consider potential future requirements for compliance monitoring (Section 5.6).

### 4.2.2 Traveller Information Interventions

Providing real-time traveller information via roadside equipment allows road operators to communicate safety critical instructions and diversion information during congestion, incidents (including severe weather), road works and other planned events. Real-time information on freeway traffic conditions and travel-times can also assist drivers in making informed decisions about their travel, such as route choice and time of travel, and support network operators with demand management during peak periods.

Real-time traveller information provision should consider three periods for communication of the information to the road users:

- pre-trip, before leaving home or work
- en route on the arterial network, before entering the freeway
- en route on the freeway network.

En route information can be provided through the use of roadside devices such as variable message signs (VMS) as well as in-car devices and services such as satellite navigation systems, radio, social media and internet. Electronic roadside signs can also be used to provide warning in advance of hazards on particular sections of the network.

The ITS elements that are required to deliver these functions are listed in Table 4.2.

<table>
<thead>
<tr>
<th>Key ITS service (intervention)</th>
<th>ITS and technology elements</th>
<th>Section</th>
</tr>
</thead>
</table>
| Roadside traveller information (i.e. travel-times and other message displays) | - freeway variable message signs (VMS)  
- arterial road VMS (including real-time information signs, RTIS\(^{12}\))  
- public transport VMS | 6.1  
6.2  
6.3 |
| Roadside hazard warning                            | - advance warning flashing signals including over-height vehicle detection and warning | 6.4 |
| Non-roadside traveller information                | - pre-trip and in-car traveller information systems             | 6.5 |

MF design should also consider other means of providing information to road users, such as through fixed signing and lane markings (Section 6.6).

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\(^{12}\) These signs are also referred to as RC3 when used to support the deployment of freeway ramp signals (Section 5.1).
4.2.3 Network Intelligence Interventions

Network intelligence functions are fundamental to MF operations. Real-time network intelligence involves the collection and analysis of traffic and other data to support the operation of control and traveller information interventions as well as incident detection and verification. This usually involves automated data feeds. Traffic data is also used for real-time and historic network intelligence to enable system performance management and freeway performance evaluation.

The ITS or technology-based elements that are required to deliver these functions are listed in Table 4.3.

Table 4.3: Key ITS services delivering network intelligence functions

<table>
<thead>
<tr>
<th>Key ITS service (intervention)</th>
<th>ITS and technology elements</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time traffic data collection</td>
<td>• vehicle detectors (on mainline and ramps)</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>• arterial road traffic data (SCATS data)</td>
<td>7.3</td>
</tr>
<tr>
<td>Travel-time calculation</td>
<td>• travel-time calculation*</td>
<td>7.5</td>
</tr>
<tr>
<td>Incident detection</td>
<td>• closed circuit television (CCTV) cameras</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>• automated incident detection system (AIDS)*</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>• emergency telephones (for reporting)</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>• communications and data sharing with internal and external stakeholders</td>
<td>7.7</td>
</tr>
<tr>
<td>Incident verification</td>
<td>• CCTV cameras</td>
<td>7.2</td>
</tr>
<tr>
<td>Real-time environmental data collection</td>
<td>• environmental monitoring systems</td>
<td>7.8</td>
</tr>
</tbody>
</table>

* Note: These elements may not require installation of additional field equipment. For example, the function may be delivered through the application of algorithms to traffic data from vehicle detectors.

4.2.4 Foundation Infrastructure

The foundation infrastructure consists of the information and communication technology (ICT) infrastructure and systems that are essential for successful operation of the control, traveller information and network intelligence functions of MF.

The ITS and technology elements that provide MF foundation infrastructure are listed in Table 4.4.
Table 4.4: ITS and technology elements for MF foundation infrastructure

<table>
<thead>
<tr>
<th>ITS and technology elements</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>communications network</td>
<td>8.1</td>
</tr>
<tr>
<td>power network</td>
<td>8.2</td>
</tr>
<tr>
<td>traffic operations centre (TOC)</td>
<td>8.3</td>
</tr>
<tr>
<td>MF control system</td>
<td>8.4</td>
</tr>
<tr>
<td>freeway performance evaluation</td>
<td>8.5</td>
</tr>
<tr>
<td>system performance management</td>
<td>8.6</td>
</tr>
<tr>
<td>other considerations</td>
<td>8.7</td>
</tr>
</tbody>
</table>

Foundation infrastructure should also any potential civil modifications e.g. ramp layout / design, to assist with retrofitting of MF interventions.

4.3 Intervention Priorities

Main Roads has developed a general framework and prioritisation for determining which ITS interventions are to be incorporated in MF design in WA. This is based on existing evidence of the effectiveness of different MF interventions implemented by VicRoads and international agencies.

In alignment with the MF Policy Statement (Main Roads 2012a), the selection of technology and operational strategies should be driven by the nature of the problems as identified by network analysis based on validated data.

ITS interventions should be considered for deployment at two levels dependent on the annual average daily traffic volumes (AADT) of the section of freeway and the occurrence of flow breakdown and congestion. The two levels are foundation level of ITS and Managed Freeways.

Main Roads currently defines moderately to heavily trafficked roads as those with an AADT volume equivalent to ≥ 60,000 veh. This value is typically used as a general guideline for application of ITS currently deployed on Main Roads’ network (e.g. vehicle detectors).

The AADT value does not take into account that different carriageways have different numbers of lanes, which may affect whether there is likely to be sufficient lane volumes for flow breakdown to occur. Given that currently Main Roads is upgrading many existing freeway sections to three-lane carriageways, it is proposed that the use of lane volumes as a threshold may be more appropriate. For a two-lane carriageway, this equates to 15,000 veh/lane using the existing definition. This value corresponds to a peak hourly flow below the value at which flow breakdown is likely to start occurring (refer Section 3) and therefore is as an appropriate guide to screen the existing freeway network and identify any sections which are reaching the threshold of the need for MF treatments.
4.3.1 **Foundation Level of ITS**

Main Roads' policy is that all freeways will, as a minimum, have real-time network intelligence and monitoring capabilities, and provision for higher order MF interventions when needed. This means that all current and future projects on the freeway network should incorporate a foundation level of ITS. This will also include provision of roadside traveller information where appropriate.

The **foundation level of ITS** applies to all lightly to moderately trafficked carriageways experiencing an AADT equivalent to < 15,000 veh/lane (based on current volumes).

Appendix A provides a summary of the warrants and approval guidelines for deployment of specific ITS interventions, including relevant foundation infrastructure, at this foundation level. These should be considered the minimum requirements for all existing and future freeways (including existing roads to be upgraded to freeway standard).

Consideration should also be given to the site-specific geometric road design needed to support the retrofitting of MF, particularly in relation to control interventions that are likely to be considered for future implementation on the freeway section, if it is cost-effective to do so. For example, consider ramp layouts and design requirements for future installation of ramp signals and the design implications of future deployment of cantilever or gantry structures for lane use and speed management.

4.3.2 **Managed Freeways**

For the purpose of this document, a Managed Freeway is a freeway comprising well-designed infrastructure and where out of the higher order ITS interventions (i.e. above foundation-level ITS) at least coordinated ramp signals have been applied as appropriate in order to achieve Main Roads' objectives for optimal freeway performance. Additional interventions may also be applied as appropriate.

**Managed Freeway** requirements apply to all moderately to heavily trafficked carriageways with an AADT equivalent to ≥ 15,000 veh/lane (based on current volumes), as there is the likelihood that flow breakdown may occur once these volumes are exceeded.

MF should also be considered on sections of freeway where flow breakdown and congestion occurs on a recurrent basis (i.e. due to oversaturation) at values lower than this threshold, as determined by freeway traffic analysis. An indicator of recurrent congestion is when average peak period travel speeds are approximately 60% or less of the posted speed limit.

Appendix B provides a summary of the warrants and approval guidelines for deployment of specific ITS interventions for MF sections. These are relevant for all existing and future freeways (including existing roads to be upgraded to freeway standard).

As general guidance for MF design, where possible, all critical mainline bottlenecks causing recurrent congestion should be ameliorated through suitable geometric design improvement options.

**Minor geometric mainline improvements or ramp modifications** (i.e. civil upgrades) should first be investigated to improve the operational efficiency of the freeway. Examples include:

- additional lane to address a localised lane drop e.g. to rectify abrupt lane drop just after an exit ramp (in some cases this may involve significant geometric improvements)

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13 Existing and future freeway standard roads within WA. Existing freeways in WA include Kwinana Freeway, Mitchell Freeway and Graham Farmer Freeway. MF will also be considered for roads which are to be upgraded to freeway standard in the future, for example current planned upgrades include Roe Highway, Reid Highway and Tonkin Highway.
• increase in exit ramp storage to prevent vehicles queuing on mainline
• increase in entry ramp length for improved acceleration to aid merging
• auxiliary lane to cater for high on / off flows between two interchanges (if traffic analysis indicates it will be highly utilised as otherwise there will be a limited effect on capacity).

Existing design strategies for **lane markings and fixed signing** such as directional signing should also be reviewed to identify opportunities to improve operational efficiency and reduce the probability of flow breakdown, particularly near interchanges.

If localised geometric improvements are practically, economically or politically unfeasible, or if traffic modelling still indicates that recurrent flow breakdown and congestion will occur after minor civil upgrades have been undertaken, then ITS and technology-based control interventions will need to be investigated alongside mainline widening options. A successful MF scheme is likely to require a combination of geometric improvements / civil upgrades and ITS and technology interventions.

**Deployment of control interventions**

The first preference is to provide system control to achieve and sustain existing capacity of the infrastructure through **coordinated ramp signalling (CRS)**. This is because CRS aims to maintain mainline traffic density (occupancy) at or near critical density (occupancy) by controlling the inflows thereby avoiding flow breakdown and congestion. CRS also has the capacity to work towards restoring the traffic flow faster, in case of flow breakdown due to an unplanned event such as a traffic incident. CRS is a route-based treatment that can include freeway-to-freeway ramp signals.

Isolated ramp signals should also be investigated to address localised problems.

**Variable speed limits (VSL)** should then be considered to support CRS in sustaining existing capacity on a route-wide basis and traffic control for queue protection and incident management.

Following consideration of CRS and VSL interventions, if there is still a requirement for additional ‘physical’ capacity on the freeway section to satisfy the agreed design volumes within the planning horizon, then **mainline widening solutions** as well as ITS solutions should be investigated and compared for effectiveness. **Lane use management systems (LUMS)**, integrated with variable speed limits, can be used to implement operational and incident management strategies that enable dynamic utilisation of the full pavement asset, to provide additional capacity as required i.e. on a full-time basis (**all lane running, ALR**) or part-time basis during periods of high demand (**part-time emergency lane running, ELR**). Benefit-cost analysis, including whole-of-life-cycle costing for ITS elements and sustainability considerations, should be undertaken when comparing ITS solutions with geometric improvements / civil upgrades.

LUMS, integrated with VSL, can be deployed for the primary purpose of facilitating incident and event management.

Note: For the WA freeway network, except the freeway sections in and adjoining Perth City, the existing lane configuration comprises two to three lanes in each direction, which was considered to be adequate to cater for the anticipated demand within the original planning horizon. However, as such two-to-three lane freeway sections are approaching their original planning horizon, they also either have approached or are approaching their full operational capacity due to increasing demand. In future planning of freeway upgrades in a new planning horizon, such two-to-three lane sections may be considered for additional lanes (capacity) if they are to cater for future demand, where it is practically and economically feasible to provide such additional capacity. However; a point in time will be reached, where further expansion of the freeway would not be feasible or desirable due to physical, environmental, political or economic reasons, as in the case of the
freeway sections in and adjoining the city. MF interventions, including CRS and use of the emergency lane as a running lane (requiring LUMS integrated with VSL), should be then considered where they provide cost-effective capacity improvements. The lane configuration beyond which a freeway section is not feasible for further physical expansion may be considered as the ‘ultimate configuration’ (for the purpose of this document).

**Enhanced level of provision of traveller information and network intelligence interventions**

Managed Freeways should incorporate an enhanced level of roadside traveller information. Information interventions such as **freeway and arterial road variable message signs, VMS,** play an important part in managing traffic through use of real-time travel-time and freeway condition information to influence driver route choice.

A Managed Freeway will also require greater provision of network intelligence interventions such as **vehicle detectors and CCTV,** to support the operation of the control and information interventions.

### 4.4 Design-life Assessment

Due to the nature of ITS interventions, MF may require different design-life assumptions to those used for traditional road projects undertaken by Main Roads.

Determination of the design life for MF interventions should consider various factors, including (but not limited to):

- level of civil works within MF design
- current expected life of existing road
- availability of funding.

The following principles may be considered as general guidance, however the detailed assessment should be discussed with Main Roads during the project planning and development stage:

- If the MF design incorporates substantial civil works as well as CRS, then a design life of at least ten years and up to twenty years should be considered (i.e. cater for traffic volumes ten to twenty years after opening).
- If the MF design incorporates primarily ITS interventions with minimal civil works, then there may be scope to consider a shorter design life of seven to ten years.

### 4.5 Impact of Peak Spreading on Peak-hour Volumes

Traditionally, traffic engineers have assumed peak hour volumes as 10% of the Annual Average Weekly Traffic (AAWT) volumes, but with increasing congestion and accompanying peak spreading, the peak-hour / daily volume ratio is decreasing. Data analysis suggests that this ratio is currently in the order of around 8% for Perth’s freeways and key arterials. With congestion continuing to increase, this ratio is likely to decline further. This should be considered when determining realistic assumptions for calculations of future time horizons.
MF control interventions should be considered for deployment on moderately to heavily trafficked freeways with an AADT equivalent to ≥15,000 veh/lane (based on current volumes) and/or freeway sections where there is already recurrent flow breakdown and congestion (i.e. due to oversaturation). An indicator of recurrent congestion is when average peak period travel speeds for a corridor are approximately 60% or less of the posted speed limit.

Intervention warrants should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes.

The control interventions should be applied to a freeway route where the warrant is met at a critical bottleneck for the route i.e. the warrant may not have to be met across the entire section of the route for the intervention to be applied. In many cases, a route treatment may be necessary to prevent flow breakdown at the critical bottleneck.

### 5 Freeway Ramp Signals

Freeway ramp signals are traffic signals provided on entry ramps to control the access to the freeway in a measured and regulated manner in order to manage the freeway traffic flow and prevent congestion. Ramp signals can be operated under both an isolated and a coordinated level of control and can also be applied to freeway-to-freeway interchanges, as described in the following sub-sections.

Note: Refer to VicRoads’ *Managed freeways: freeway ramp signals handbook* (2010b) for detailed design guidance on ramp signalling, including the minimum requirements for other ITS interventions providing network intelligence and traveller information functions that support ramp signal deployment. Main Roads has produced a ‘Supplement’ (2012c) to the VicRoads’ publication which must be read in conjunction.

#### 5.1.1 Coordinated Ramp Signals

Coordinated ramp signals (CRS) use a dynamic approach that incorporates data from a larger section of the freeway as well as a number of entry ramps to manage the freeway traffic flow. This operation is able to regulate the entry of traffic from a number of ramps to balance the flows between ramps and regulate the freeway traffic demand, by matching traffic inflows from a group of ramps to the capacity of a critical bottleneck downstream.

CRS assist in maintaining the critical occupancy (density)\(^{14}\) of the freeway mainline and reducing the possibility of flow breakdown through the following principal actions:

- managing the headway of entering traffic, i.e. an evenly distributed flow of traffic into the merge area
- managing the flow rate of entering traffic when the freeway is near capacity, i.e. limit the entry flows to avoid transition to an unstable condition at the merge area
- ensuring the overall mainline traffic volume does not exceed the bottleneck capacity at critical bottlenecks, i.e. prevent or delay flow breakdown at a bottleneck.

CRS also have the capacity to restore the traffic flow faster in case of flow breakdown due to an unplanned event such as a traffic incident.

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\(^{14}\) The critical occupancy (a surrogate for density in control systems as it is easier to measure) at which capacity flow occurs is used to manage freeway flow, as unlike capacity it is found to be fairly stable even under adverse weather conditions. The occupancy measurement is considered to be the most appropriate parameter for optimising throughput, rather than speed or flow rate.
Warrants and approval guidelines

CRS should be implemented as a corridor-wide adaptive system at freeways where the peak-period traffic flow rates are ≥ 1,800 pc/h/lane (approx. 1,700 veh/h/lane with 10% heavy vehicles)\(^{15}\) for the mainline traffic between interchanges.

In addition CRS are recommended where:

- congestion and flow breakdown is occurring at a number of bottlenecks over a length of freeway
- flow breakdown occurring at a particular location cannot be addressed by an isolated ramp meter, i.e. freeway flow causing the flow breakdown results from a combination of a number of upstream entry ramps
- analysis indicates that flow breakdown already occurs on the freeway and traffic volumes are ≥ 1,800 pc/h/lane (approx. 1,700 veh/h/lane with 10% heavy vehicles).

Some freeway sections will have lower forecast volumes at some midblock sections then the warrants above due to the entry and exit volumes at each interchange. In a route based approach, even individual entry ramps in sections that do not meet the criteria for ramp signals would generally require metering as part of the CRS system, to provide sufficient control of the section where recurrent flow breakdown is occurring as a result of a critical bottleneck. If a complete treatment is not provided then access equity (i.e. balancing of queues across ramps), efficient utilisation of available storage space and effective control of the freeway flow cannot be achieved, and rat-running behaviour may be encouraged.

The determination of how many ramps are required for metering will depend on the outcomes of the freeway traffic analysis. However, the following general guidance applies:

- For managed freeways with two or three lane carriageways, at least six consecutive ramps upstream of a major bottleneck are required to be metered to complete the route-based treatment. For managed freeways with four or more carriageways and freeway-to-freeway interchanges, up to eight ramps may be required to provide effective control, subject to the entry flows involved,
- Other downstream ramps along the freeway may also need to be metered. One or two ramps downstream of a major bottleneck may be required to ensure the treated bottleneck does not just move to the next downstream interchange. This assessment is determined on the basis of demands at the downstream interchange ramps and an understanding of the coordinating algorithm’s operation (i.e. minimum flow rates).

At some locations, interfacing of the ramp signals and the arterial traffic signals, operated through SCATS, is necessary for an optimal operation of the entire road network. For example, for ramp queue overflow, where implementation of leading and lagging right-turn phases might reduce the potential for overfilling a ramp (i.e. two short right-turn phases within a cycle rather than a single

\(^{15}\) This warrant should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes. 1,800 pc/h/lane is equivalent to approx. 10% probability of flow breakdown based on data from Perth’s freeways (Section 3).

Passenger car equivalent values (pc/h/lane) are used instead of veh/h/lane values to account for presence of heavy vehicles. The vehicle mix (i.e. presence of heavy vehicles) can have an effect on traffic behaviour and there is significant variation in the proportion of heavy vehicles on WA’s freeways, ranging from 5 to 20%. In freeway capacity analysis it is therefore considered more appropriate to convert heavy vehicles to an equivalent number of passenger cars to provide consistent measures of flow. The conversions in this document assume 10% heavy vehicles and a heavy vehicle equivalency factor of 1.5 (for level terrain). However, it should be noted that factors of 2.5 and 4.5 are applicable for rolling terrain and mountainous terrain respectively.
longer phase). Integration with traffic signals is also required where there are physical constraints on ramp storage capacity and arterial roads are required to provide additional queue storage.

**Technology and installation configurations**

The core component of ramp signals is the traffic signals located at the entry ramps to the freeway. However, additional equipment is required for an effective operation of the ramp signals, including:

- signal controller
- signal support pedestals
- ramp signalling fixed regulatory signs (i.e. ‘one vehicle per green’)
- CCTV camera(s) on the entry ramp, where possible to provide visibility of the full ramp length and arterial road approaches (in case of queue overflow) and at the freeway merge
- vehicle detectors on the mainline and entry ramps, as well as the arterial roads when used for ramp storage (see below for further detail)
- electronic signs (RC1, RC2 and RC3) as required according to the guidelines provided in VicRoads’ *Managed freeways: freeway ramp signals handbook* (2010a) and the accompanying Main Roads’ Supplement (2012c), and in alignment with Main Roads’ ‘Guide for Traveller Information Displays on Variable Message Signs for Managed Freeways’ (ARRB 2012c) (see below for further detail).

Other considerations include pavement markings, power and communications infrastructure and lighting. Refer to existing Main Roads’ standards where appropriate.

Vehicle detectors provided at the mainline and entry ramp are essential for the operation of ramp signals. They should provide flow, speed and occupancy data. For ramp signals, detectors should be provided at the following locations:

- each lane on the mainline just beyond the turbulent merging area, generally at the end of the taper (principal source for ramp signal control system) approximately 330 m from the nose for both merging ramps and add-lane ramps
- approximately 80 – 100 m upstream of the entry ramp nose (stop line position) with separate detectors for the ramp and mainline traffic
- just downstream of the exit ramp nose, with separate detectors for ramp and mainline traffic
- each lane on the entry ramp immediately upstream of the stop line
- each lane at the midpoint of the entry ramp between the stop line and the ramp entrance (for queue length estimates and queue management)
- each lane at the entrance to the entry ramp (for queue length estimates and queue management)
- within ramp storage areas located on the arterial road (if required to manage ramp storage overflows)
- other mainline locations include potential bottleneck areas where traffic flow needs to be managed.

Vehicle detectors are discussed in further detail in Section 7.1. Also refer to the *Managed Freeways: Freeway Ramp Signals Handbook* (VicRoads 2010b) for additional guidance on the requirements for vehicle detectors to support freeway ramp signals.
As freeway ramp signals are part-time traffic control devices, drivers need to be advised on the operation of the signals. As a result, electronic signage should be operated as part of the ramp signals to provide the following information:

- **RC1** – warning and regulatory signs provided on the approaches to the arterial / entry ramp intersection providing information on the operation of the ramp signals and closure of the freeway ramp.
- **RC2** – warning signs provided on the entry ramp where there is restricted sight distance to the ramp signals providing information on the operation of the ramp signals.
- **RC3** – real-time information signs provided on the arterial roads approaching the freeway providing real-time information on the freeway condition, including travel-times, level of congestion, incidents and events (Section 6.2). These signs may not be justified on the approach to all ramps i.e. due to lower turning movements onto the freeway or where downstream travel-time data is not available, in which case an advanced RC1 may be provided on the approach to supplement the RC1 sign at the intersection.

**Key dependencies**

CRS are related to the following other MF interventions:

- **Control**: isolated ramp signals, freeway-to-freeway ramp signals, VSL, LUMS, priority vehicle facilities and arterial road traffic signals.
- **Traveller information**: VMS and pre-trip and in-car traveller information.
- **Network intelligence**: vehicle detectors and CCTV.

### 5.1.2 Isolated Ramp Signals

Isolated ramp signals, or local ramp signals, operate independently and do not interact with adjacent entry ramps. They are effective at locations where entering traffic causes flow breakdown in the mainline flow at an isolated bottleneck that generally has no impact on, or from, other interchanges. Their function is to manage the entering rate of traffic to overcome the impact of large uncontrolled platoons of traffic entering the freeway. Operation should be dynamic for maximum effectiveness.

**Warrants and approval guidelines**

Isolated ramp signals may be effective in providing reductions in merging problems and improvement of freeway traffic flow where there is an isolated high merging flow. However, they have limited functionality and ability to balance operation along a route. Isolated ramp metering should be considered when:

- breakdown of the mainline freeway flow is localised and clearly associated with platoons of traffic entering at a particular ramp
- localised flow breakdown is unrelated to downstream congestion or upstream flows
- where a high number of peak-period, congestion-related crashes are occurring i.e. rear-end, sideswipe and lane-changing crashes; this may be near a heavy merge, weave or diverge or on a physically constrained location such as a bridge or a tunnel without a full emergency lane
- redistribution of traffic to other adjacent ramps is unlikely or negligible.

As with CRS, there may also be requirements for integration with arterial road traffic signals (SCATS).
Technology and installation configurations

See requirements for CRS (Section 5.1.1).

Key dependencies

Isolated ramp signals are related to the following other MF interventions:

- **Control**: CRS, freeway-to-freeway ramp signals, LUMS, VSL, priority vehicle facilities and arterial road traffic signals.
- **Traveller information**: VMS and pre-trip and in-car traveller information.
- **Network intelligence**: vehicle detectors and CCTV.

5.1.3 Freeway-to-Freeway Ramp Signals

Freeway-to-freeway ramp signalling may be required to provide control of traffic flows at a freeway-to-freeway interchange for management of a critical bottleneck near the interchange or to complete a route-based MF ramp signalling treatment. This may be particularly important if there is limited ability to control traffic upstream of the interchange.

VicRoads' *Managed freeways: freeway ramp signals handbook* (2010b) states that the preferred strategy for managing the freeway-to-freeway merge and downstream section of the freeway is through metering of the upstream entry ramps from arterial roads. This was based on an assumption that it is desirable to provide uninterrupted freeway flow at such interchanges and due to the fact that they may be difficult locations for provision of widening and storage facilities. However, this assumption has been challenged and particularly in WA the use of freeway-to-freeway ramp signals may be necessary as there may not always be sufficient upstream ramps or entry ramp flow volumes to provide effective control at the interchange.

Generally, to manage mainline traffic flow all upstream entry flows need to be controlled. If flow breakdown does occur on the managed freeway this would impact not only the managed freeway but also the traffic from the entering freeway. Where freeway-to-freeway ramp signalling is provided it therefore would only operate when needed and uninterrupted free-flow operation would be available at other times.

Depending on the nature of the interchange, different approaches may be relevant. For example, at joining freeways where there are high flows from the intersecting freeway travelling in the same direction along the managed freeway (i.e. low split in volumes at the interchange), then upstream metering of the entry ramps may provide significant control (Figure 5-1). This is because the traffic from these ramps generally makes a significant contribution to the flow entering the managed freeway.

However, metering the freeway-to-freeway ramp may be required to achieve the desired level of access control for some joining or crossing freeways. This applies to the situation where:

- ramps immediately upstream of the interchange generally make a relatively lower traffic contribution to the turning flows at the interchange
- metering of the upstream ramps on the intersecting freeway also disadvantages traffic that is not exiting to the Managed Freeway.

An example of where freeway-to-freeway ramp signalling should be applied at crossing freeways is illustrated in Figure 5-2. It may also be relevant for joining freeways with high splits in volumes in each direction along the Managed Freeway.
Managed Freeways Provision Guidelines

Figure 5-1: Controlling vehicle movements at the freeway-to-freeway interchange using upstream ramp signals

Source: VicRoads (2010b).

Figure 5-2: Controlling vehicle movements at the freeway-to-freeway interchange using freeway-to-freeway ramp signals

Source: VicRoads (2010b).

Note: It may also be possible to use VSL to assist ramp signals in controlling a freeway-to-freeway interchange. Further research is required to develop the appropriate algorithms.
Warrants and approval guidelines

The requirement for ramp signals to control freeway-to-freeway movements should be based on detailed analysis of origin-destination flows at the interchange and upstream entry ramp flow rates, as well as a good understanding of the ramp signal control system operation.

In some locations, sufficient control of flows at the freeway-to-freeway interchange may be achieved through metering of upstream ramps.

Freeway-to-freeway ramp signals should be used if minimum flow rates from upstream ramps are insufficient to control flows at the interchange (i.e. make lower relative contributions to turning flows at the interchange) and where upstream metering disadvantages a high proportion of traffic exiting the freeway.

Technology and installation configurations

The same guidance applies as for CRS (Section 5.1.1).

Key dependencies

Freeway-to-freeway ramp signals are related to the following other MF interventions:

- **Control**: CRS, isolated ramp signals, LUMS and VSL.
- **Traveller information**: VMS and on-trip and in-car traveller information.
- **Network intelligence**: vehicle detectors and CCTV.

5.2 Variable Speed Limits

Variable speed limits (VSL) are used to improve road safety and traffic flow by displaying appropriate speed limits for varying freeway and traffic conditions on electronic signs along or above the freeway. The key applications of VSL are:

- **Incident and event management (primarily in conjunction with LUMS)** – used to control vehicle speeds during incidents, road works or other events. The signs manage the traffic travelling towards or along the affected area. They can be used in conjunction with LUMS (Section 5.3) to reduce speeds on the approach to road closures or when passing a closed road section. Reduced speeds help to protect road users and provide a safer working environment for road workers and incident responders at the affected road sections.

- **Queue protection** – used to slow down vehicles in advance of congestion caused by high demand or incidents. It warns vehicles on the approach to the congestion and reduces the risk of high-speed traffic encountering the queue. Therefore it reduces the likelihood of (secondary) incidents, particularly rear-end crashes.

- **Environmental** – speed limits can be adjusted to improve road safety for vulnerable road sections such as bridges and tunnels during adverse weather conditions (e.g. heavy rain or high wind speeds). They can also be used to achieve local environmental benefits, such as improved air quality, by reducing the speed limit to an optimum, when the emission levels are expected to be the lowest.

VicRoads undertook a review of international research on the effectiveness of VSL (VicRoads 2012). The review indicated that VSL can also deliver some capacity and traffic flow benefits. This is achieved by controlling the speed and flow of traffic before reaching a critical threshold i.e. traffic is slowed in a controlled manner to maintain steady flow conditions with increased capacities and throughput. In addition, traffic flow benefits are achieved through reductions in secondary incidents as a result of queue protection.
However, the review highlighted that VSL are generally considered to primarily delay rather than prevent the onset of congestion and the timing of VSL activation is critical otherwise adverse effects can occur. Also, many studies demonstrating benefits are for high-speed (> 120 km/h) or rural motorways and the applicability to Australian freeways is questionable. The integration of VSL with CRS may produce the best benefits but there is limited evidence to date.

**Warrants and approval guidelines**

VSL should be investigated as a route treatment to provide enhanced control and support to CRS in sustaining maximum operational capacities (e.g. can assist in enabling higher densities prior to flow breakdown where demand is difficult to manage with ramp signals).

In this context, they should only be considered for sections of freeway with CRS already in operation that are achieving peak period traffic flows near operational capacity ≥ 2,000 pc/h/lane or approximately 1,900 veh/h/lane with 10% heavy vehicles\(^\text{16}\) i.e. flows at or near operational capacities.

Note: Appropriate algorithms will need to be developed to provide integrated CRS and VSL control of mainline flows. Research is currently being undertaken in this area by the Technical University of Crete. Further guidance will be provided when available.

VSL may also be considered for implementation independently of CRS in the following situations:

- to support the LUMS environment (where integrated use of lane use signals for both speed and lane use management is recommended due to the improved functionality at marginal additional cost)
- as a safety treatment if serious accidents are occurring, e.g. high rates of non-congestion-related incidents\(^\text{17}\)
- as a safety treatment to lower the speed limit to match operating speeds during congestion, including back of queue protection
- as a safety treatment where there are other safety imperatives for the ability to communicate reduced speed limits (e.g. in tunnel environments or on bridges where adverse weather conditions such as high winds and reduced visibility due to fog are commonly experienced)
- to assist with event management where traffic management is frequently provided for planned events (e.g. abnormal-sized load escorts, sporting events and road works)
- to provide consistent route management along MF with VSL in operation on some sections (including at freeway-to-freeway interchanges).

High-speed freeways (i.e. > 100 km/h) should be prioritised for VSL, where they are likely to deliver most capacity and safety benefits.

**Technology and installation configurations**

\(^{16}\) Warrants should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes. Even if this warrant is not met on all sections within the route, a route-based treatment may still be necessary for system control.

Passenger car equivalent values (pc/h/lane) are used instead of veh/h/lane values to account for presence of heavy vehicles. The conversions in this document assume 10% heavy vehicles and a heavy vehicle equivalency factor of 1.5 (for level terrain). However, it should be noted that factors of 2.5 and 4.5 are applicable for rolling terrain and mountainous terrain respectively.

\(^{17}\) It is expected that deployment of CRS will significantly reduce the occurrence of congestion-related incidents and, as such, VSL would only be required as an additional intervention to CRS to improve safety in relation to speed-related incidents.
VSL are communicated to road users through illuminated signs which display the mandatory speed limit. The VSL signs should comply with the format and colours specified for VSL in AS 1742.4 and should have the functionality to show three numbers in roundels (Figure 5-3).

Note: To increase the attention to the signals it is recommended that there is functionality for flashing roundels and / or additional yellow flashing lights (wig-wags) located at each corner of the sign. Main Roads’ policy for the use of flashing roundels and wig wags on VSL in MF schemes is still under development as of June 2012. Main Roads should be consulted as appropriate and further guidance will be provided when available.

VSL signs should be installed as follows:

- on both sides of the mainline carriageway (i.e. side-mounted or cantilever) for carriageways:
  - with two lanes
  - with up to three lanes and low to moderate truck volumes (e.g. consider where > 7% of heavy vehicles)
  - short sections of carriageways with four lanes, only if the fourth lane is an auxiliary lane and the remainder of the freeway would otherwise have side mounted VSL
  - on entry and exit ramps
  - in tunnel environments or other sections with restricted visibility, where overhead mounting could result in compromised or confusing signing.

- as overhead signs (i.e. gantry-mounted or cantilever) for carriageways:
  - on freeway sections that are not suitable for side mounting in line with guidance above
  - on sections where LUMS is required.

For the integration of VSL with LUMS, the technology and installation configurations for LUMS as described in Section 5.3.1 apply.

Where overhead signs are recommended on the basis of either LUMS or VSL, it is preferred that integrated lane use and speed management (i.e. use of same LUS) is provided due to the
improved functionality at marginal additional cost. Note: Where VSL is integrated with LUMS, a speed limit above the road indicates that lane is available for use.

In tunnels, integration of VSL into the lane use signals is also preferred; however, if due to vertical clearance, overhead signs or integration with LUMS is restricted, side-mounted VSL signs might be considered.

Longitudinal spacing of VSL on the mainline is comparable to the requirements for LUMS (refer to Section 5.3.1).

For a section of freeway with VSL in operation, side-mounted VSL signs should be installed on the entry ramps. They should be installed on both sides of the ramp in conjunction with the MR-GE-22 (Start of Fwy) supplementary sign as per the Technical Guidelines – Speed Zoning (Main Roads 2011a). When implemented at entry ramps with ramp signals, they should be located downstream of the ramp signals as per Main Roads' standard drawings (Note - As of June 2012 these have yet to be approved).

Note: Refer to VicRoads’ ‘Managed Freeways handbook for LUMS, VSL and traveller information’ (2012) for further guidance.

**Key dependencies**

VSL are related to the following other MF interventions:

- **Control**: freeway ramp signals and LUMS.
- **Traveller information**: VMS and pre-trip and in-car systems.
- **Network intelligence**: vehicle detectors and CCTV.

### 5.3 Lane Use Management Systems

Lane use management systems (LUMS) allocate and manage lane use across the carriageway. Electronic signs, referred to as lane use signs (LUS), indicate the status of the lanes to road users, including lane open, diversion and lane closed.

LUMS are used to implement various operational strategies on the network to achieve capacity improvements through dynamic use of the full pavement asset, including the emergency lane, on a full-time or part-time basis. They can also be used to implement reversible lane systems or specifically for incident and event management. The warrants for each of these applications are described in the following sub-sections.

To provide additional functionality with marginal additional costs, LUMS are usually combined with VSL (Section 5.2) resulting in integrated speed and lane use management. The speed and lane use control is provided via shared LUS that are generally mounted above each running lane. An integrated system enables the operators to manage the traffic flow in a clear and efficient way, for example through the use of both lane closures and reduced speed limits to direct traffic safely around an incident or event.

#### 5.3.1 All Lane Running

All lane running (ALR) – also referred to as full-time emergency lane running (full-time ELR) – is when there is full pavement utilisation on a permanent basis. This involves the conversion of the emergency lane to a permanent running lane or a freeway that is constructed without an emergency lane. This freeway geometry effectively provides an additional running lane to increase the capacity of the freeway. When applied as an additional lane for extensive lengths, the extra capacity could be approximately 2,000 veh/h (Austroads 2009a). LUMS (integrated with VSL) are
used to enable dynamic control of lane use and speed limits when lane closures are required as a result of an incident or event.

The emergency lane can also be converted to a running lane to address isolated or localised congestion issues, by providing additional capacity:

- between interchanges (i.e. an auxiliary lane) – provision of additional capacity will minimise the need for drivers to interact with the mainline traffic flow
- at exit ramps to increase the available storage area – provision of additional storage on the emergency lane upstream of exit ramps where queues from the traffic signals frequently extend back on to the mainline freeway
- at merge areas of entry ramps to extend the acceleration lane to aid merging – provision of additional acceleration length at locations where the merge facilitates are inadequate and create a bottleneck
- at lane drops – provision of extended length of a lane to better facilitate merging of vehicles back into the main stream.

Due to the increased safety risks of full pavement utilisation on a permanent basis, the following key principles should be adhered to when designing freeways with ALR:

- minimise the likelihood of crashes and breakdowns occurring through effective design (e.g. by improving signing and lane marking, eliminating lane drops and lane gains and minimising lane changing and weaving areas)
- detect and clear incidents and vehicle breakdowns as quickly as possible
- manage traffic around an incident in terms of speed and lane use, through deployment of LUMS where appropriate
- alert and divert drivers from the affected location as early as practicable through provision of traveller information.

These actions help to reduce the resulting traffic congestion from blockages on the carriageway and reduce the risk of secondary incidents, particularly rear-end crashes.

Warrants and approval guidelines

ALR should be considered for deployment as a route or localised treatment when required to provide additional 'physical' capacity and it is not practically, economically or politically feasible to undertake significant geometric improvements / civil upgrades. Environmental and sustainability implications should be assessed. It may also be appropriate to use ALR as an interim solution before widening can take place. Where ALR is to be used as an interim solution, consideration should be given to the practicality of establishing the future road works traffic management necessary for widening.

ALR should be considered on Managed Freeway sections if the maximum operational capacity (i.e. 2,200 pc/h/lane which equates to approx. 2,100 veh/h/lane with 10% heavy vehicles)\(^\text{18}\) is being exceeded for significant periods of the day or there are unacceptable impacts of Managed Freeways on the connecting road network. For example, if the following conditions are met:

\(^{18}\) This warrant is only likely to be achieved on a Managed Freeway comprising well-designed infrastructure with CRS in operation. 2,100 veh/h/lane is equivalent to approx. 85% flow breakdown probability according to Brilon et al (2005). Warrants should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes. Even if this warrant is not met on all sections within the route, a route-based treatment may still be appropriate.
• if average mainline peak period travel speeds are below 65 km/h are on sections with CRS ramp delays exceed maximum thresholds of four minutes.

ALR can provide a cost-effective alternative to civil upgrades and part-time ELR; however, there may be safety risks associated with not having an emergency lane on a permanent basis. This may be unjustifiable if there are long periods when demand is low and there is no requirement for additional capacity.

ALR may be more appropriate than part-time ELR if there is high demand and congested conditions for over two hours a day.

There may be no requirement for deployment of LUMS for short sections of ALR. For example, sections less than or just over 500 m may not require the deployment of LUMS, since recommended maximum gantry spacing is 500 m. This could include sections over bridges or between closely spaced interchanges. The requirement for LUMS should be assessed on a case-by-case basis since there may be specific requirements for road environments such as tunnels.

LUMS may be implemented at lower traffic volumes then those described in the warrants above for safety reasons, as covered in Section 5.3.4.

Technology and installation configurations

For existing carriageways, the conversion of the emergency lane to a running lane requires the shoulder lane to meet at least the minimum requirements for a running lane. This may require upgrades of pavement strength and depth, surface treatments, verge treatments and amendments to fixed signage and lane marking and increased number of drainage pits where the road is kerbed. Reduced lane widths may be considered for constrained sites only where 3.5 m lane widths cannot be accommodated (e.g. reduction to 3.35 m width lanes for sections with 100 km/h speed limits). Further reductions in lane width may require reduced speed limits depending on the length of the section and other factors.

Note: There may be other requirements for reduced speed limits on MF sections with ALR in operation. Main Roads’ policy in this area is still under development as of June 2012. Main Roads should be consulted as appropriate and further guidance will be provided when available.

Sections of the freeway with ALR, or no emergency lane, require additional facilities to be deployed for active management of any potential adverse safety risks. In addition to the possible requirement for LUMS, the following provisions should be made:

• emergency stopping bays, with emergency telephones at the left side of the road, at appropriate spacing (for MF sections where CRS and LUMS is deployed)\textsuperscript{19}

Also, passenger car equivalent values (pc/h/lane) are used instead of veh/h/lane values to account for presence of heavy vehicles. The conversions in this document assume 10% heavy vehicles and a heavy vehicle equivalency factor of 1.5 (for level terrain). However, it should be noted that factors of 2.5 and 4.5 are applicable for rolling terrain and mountainous terrain respectively.

\textsuperscript{19} The VicRoads’ MF guidance for emergency stopping bay provision (where there is no permanent stopping lane) is that desirable spacing is 400 – 500 m, with a maximum of 1000 m (VicRoads 2012). In the UK, part-time ELR is already in operation on some sections of network and ALR is being considered for future schemes. UK guidance relevant to part-time ELR operation (Highways Agency 2009) for spacing of emergency stopping bays (referred to as refuge areas) states that they should be spaced between 600 m and 1000 m between interchanges, with an average frequency no greater than 800 m. They should also be co-located with gantries. New UK guidance relevant to ALR operation (Highways Agency 2012) states that the spacing should be such the driver is never more than 2.5 km from a refuge area.

Main Roads’ existing technical guidelines for emergency stopping bays indicates that the provision of emergency stopping bays may be viewed as an enhancement to the provision of emergency telephones only.
- enhanced surveillance and monitoring, including
  - full CCTV coverage, including all emergency stopping bays and any areas under bridges or other structures
  - vehicle detectors on all trafficked lanes, including converted emergency lane
  - vehicle detection for all emergency stopping bays (desirable)
  - AIDS with high sensitivity if required to support rapid incident detection (for consideration)
- processes and resources, including on-scene responders, to enable rapid and effective incident management response
- roadside signage (variable message signs – Sections 6.1 and 6.2, fixed signs – Section 6.5) to inform road users on the absence of an emergency lane and provide advice during incidents.

The LUMS (semi-)automatically controls the operation of the LUS through the use of algorithms, which can be combined with operation of variable speed limit signs. In addition to speed limits (where appropriate), the LUS should be able to display the symbols shown in Figure 5-4.

![Figure 5-4: LUS displays with an LUMS](image)

The note in Section 5.2 for VSL relating to use of flashing roundels and/or additional yellow flashing lights (wig-wags) to increase drivers’ attention also applies.

The LUS should be mounted over each lane on gantries, side-mounted cantilever structures or bridges and underpasses. Gantries may span each carriageway or the full width of the freeway depending on the location-specific context.

Refer to VicRoads’ ‘Managed Freeways handbook for LUMS, VSL and traveller information’ (2012) for guidance on mainline longitudinal spacing of LUS. Specifically refer to Section 2.5.2 for guidance on location and spacing of LUS near interchanges, as well as Section 2.5.3 for guidance on spacing of LUS between interchanges.

Installation of LUMS gantries or other structures should consider potential future widening of the carriageway and minimise future requirements for relocating or rebuilding gantries.

Further guidance on positioning of gantries or other structures for display of LUS is provided in Freeway design parameters for fully managed operations (Austroads 2009a).

Note: Depending on the freeway environment and project specific requirements for provision of driver information on speed and lane use, there may be a case for increased mainline longitudinal spacing of LUS then suggested in the aforementioned documents, provided it is not likely to adversely impact on safety. Further guidance will be provided by Main Roads when available, and Main Roads’ policy in this area is still under discussion and further guidance will be provided by as appropriate, until which Main Roads’ should be consulted for advice.
any proposed deviation from the existing guidance should be discussed with Main Roads at an early stage in the design process.

**Key dependencies**

ALR (using LUMS) is related to the following other MF interventions:

- **Control**: freeway ramp signals, VSL and LUMS.
- **Traveller information**: VMS and fixed signs.
- **Network intelligence**: vehicle detectors, CCTV, AIDS and emergency telephones.

### 5.3.2 Part-time Emergency Lane Running

Part-time emergency lane running (ELR) involves the part-time and controlled use of the emergency lane by traffic to provide additional capacity when demand is high. ELR can be activated at set times, for example weekday peak hours, or as required to dynamically respond to changing traffic conditions including increased traffic flows or an incident.

As with ALR, part-time ELR may be used for route treatments or to address isolated or localised congestion issues by providing additional capacity between interchanges (e.g. auxiliary lanes), on exit ramps, at entry ramp merge areas and at lane drops (refer to Section 5.3.1).

Part-time ELR requires LUMS to open and close the emergency lane to traffic as required, as well as to implement lane closures if an incident occurs when emergency lane running is in operation.

The principles for managing safety risks associated with ALR, as outlined in Section 5.3.1, also apply to the use of emergency lanes on a part-time basis. Furthermore, there are also additional risks during the transition process when opening the emergency lane to traffic.

**Warrants and approval guidelines**

Refer to warrants and approval guidelines for ALR as detailed in Section 5.3.1.

Part-time ELR can provide a cost-effective alternative to civil upgrades and reduces the safety risk associated with permanent conversion of the emergency lane to a running lane. However, the additional costs associated with the transition process when opening the emergency lane to traffic mean that part-time ELR may not always deliver a higher benefit-cost ratio to ALR.

Part-time ELR may be more appropriate than ALR if:

- there are short, sharp peaks in demand which lead to flow breakdown for a long time due to the extended recovery period
- it is prohibitively expensive to widen the road (e.g. across a bridge) but an extra lane is needed in peak periods only
- there are additional considerations that mean only part-time use of the emergency lane would significantly reduce the safety risk. For example, on sections where there is limited space to provide emergency stopping bays at desirable intervals or where there are high incident rates outside of peak hours (i.e. speed-related incidents). Note: Emergency stopping bays should still be provided at appropriate spacing within part-time ELR.

**Technology and installation configurations**

The technology and installation requirements for ALR outlined in Section 5.3.1 also apply to part-time ELR. However, for part-time ELR an additional safety process is required for managing the
transition from emergency lane to running lane. Automated surveillance and incident detection systems need to be installed and / or manual safety checks need to be performed to ensure there are no hazards on the emergency lane such as stationary vehicles, or debris. This may require the installation of CCTV cameras and AIDS.

Where used as a route treatment, ELR should be applied across interchanges facilities to ensure safe passages of the exit and entry ramps. Consideration should be given to appropriate geometric design, including signage and line markings.

Generally, other jurisdictions have used the left hand side emergency stopping lane (ESL) as the running lane. It may be possible to use the right hand side (median side) ESL as the running lane instead, subject to various considerations. For part-time use of the emergency lane this could avoid some of the problems associated with entering traffic and line marking at entry and exit ramps. However, it may encourage excessive lane changing for entry / exit and median side ESLs are sometimes narrower than the left side ESL which may be problematic. Stopping sight distance across the median on right hand curves could also be an issue, particularly if barriers are present. As a result of these concerns, it is recommended that use of the median side ESL is less desirable.

Electronic signage that indicates the operational status of the emergency lane is highly beneficial for effective operation of ELR. A red cross on the LUS above the emergency lane is not appropriate for part-time operations, therefore it is recommended that additional signs that show when an ELR is open / closed and when the ELR ends should be installed.

**Key dependencies**

Part-time ELR (using LUMS) is related to the following other MF interventions:

- **Control**: freeway ramp signals, VSL and LUMS.
- **Traveller information**: VMS and fixed signs.
- **Network intelligence**: vehicle detectors, CCTV, AIDS and emergency telephones.

5.3.3 Reversible Lanes

Reversible lanes – also referred to as tidal flow lanes – are another operational strategy that can be used to adjust lane configurations according to real-time traffic demand, to optimise the lane configuration to the current traffic flow characteristics of the freeway.

Reversible lane systems are specifically used to address recurrent congestion where there are significant imbalances in utilisation between carriageways during peak periods.

Where reversible systems are implemented, they can also be used:

- to assist response to major incidents at key infrastructure, including tunnels and bridges, or on key sections of freeway prone to incidents
- to assist with traffic management during road works including maintenance of infrastructure such as bridges and ITS field equipment.

LUMS are usually required to implement reversible lane systems.

**Warrants and approval guidelines**

Reversible lane systems can be considered for situations where:

- tidal flow patterns are observed (e.g. where over 70% of peak traffic travels in one direction)
a reduced number of lanes in the counter-peak direction can accommodate the counter-peak traffic flows.

Practical constraints may exist in applying reversible lane systems on freeway sections with a railway line between the two carriageways, as experienced on the Mitchell and Kwinana Freeways.

*Technology and installation configurations*

Reversible lane systems may use existing lanes from the opposite direction or have a separate reversible lane located in between or elevated above the existing carriageway. Separation systems between directional flows should be provided to comply with Main Roads’ Safe Systems requirements and road safety barrier guidelines. Lane use instructions should be reinforced through LUMS, variable message signs and fixed signs. In addition, for a safe operation of the reversible lane, surveillance and monitoring are essential to monitor the road section before opening of the lane for the other direction.

The LUMS technology and installation configurations relating to the functionality of lane use signal technologies, mounting structures and longitudinal spacing are the same as those outlined in Section 5.3.1.

*Key dependencies*

Reversible lanes are related to the following other MF interventions:

- **Control**: LUMS.
- **Traveller information**: VMS and fixed signs.
- **Network intelligence**: vehicle detectors, CCTV and AIDS.

*5.3.4 LUMS for Incident and Event Management Only*

LUMS can also be deployed solely to provide traffic management and improve safety during incidents, road works and events. LUMS can divert traffic around an incident or event on specific lanes of the freeway to provide access for incident responders (e.g. emergency services) and road workers, and protect the affected location. This reduces the likelihood of secondary incidents.

*Warrants and approval guidelines*

In addition to freeway sections where LUMS is required to facilitate full pavement utilisation (i.e. ALR or part-time ELR) or for reversible lane systems, LUMS should also be considered for deployment on freeway sections where:

- there are additional safety risks which could be reduced by lane use management (e.g. tunnels or large bridges without an emergency lane)
- there are high rates of non-congestion related incidents
- where traffic management is frequently provided for planned events (e.g. abnormal-sized load escorts, sporting events and road works)
- there is increased likelihood that a broken down vehicle will not be able to reach the emergency lane or emergency stopping bay, due to a combination of number of lanes and traffic density

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20 LUMS should not be required for management of congestion-related incidents on MF as these should be addressed through CRS.
to provide consistent route management along the MF with LUMS in operation on some sections (including at freeway-to-freeway interchanges).

This may lead to the application of LUMS for safety reasons on freeway sections with lower traffic flows then used for the warrants for ALR and part-time ELR as described in Sections 5.3.1 and 5.3.2.

LUMS should be applied across all running lanes, including the emergency lane even if not used as a running lane for capacity improvements, in order to assist diversion of traffic during an incident.

**Technology and installation configurations**

The LUMS technology and installation configurations relating to the functionality of lane use signal technologies, mounting structures and longitudinal spacing are the same as those outlined in Section 5.3.1.

**Key dependencies**

LUMS for incident and event management is related to the following other MF interventions:

- **Control**: freeway ramp signals (for ramp signal response to lane or freeway closures and emergency vehicle access when ramps are operating), other LUMS applications and priority vehicle facilities.
- **Traveller information**: VMS and pre-trip and in-car systems (for warning of lane or freeway closures and incident information).
- **Network intelligence**: vehicle detectors, CCTV, AIDS.

### 5.4 Priority Vehicle Facilities

Priority or high-value vehicles include emergency vehicles, public transport vehicles, freight, high occupancy vehicles (T2 / T3) and taxis. The following priority facilities can be provided to improve the service level on freeways for these vehicles:

- priority lanes at entry ramps with ramp signals, consisting either of a free-flow lane or metered lane
- mid-block priority lanes on freeway sections, which may allow permanent or dynamic access (i.e. during peak hours) to high-value vehicles.

The advantages and disadvantages of two different approaches for priority lanes at entry ramps with ramp signals are as follows.

- **Free flow priority lane** – has the advantage that high-value traffic does not have to stop on the entry ramp, which can be particularly beneficial to large, heavy vehicles which require longer distances to decelerate and accelerate. The disadvantage of a free-flow priority lane is that uncontrolled entry flow can cause problems for mainline control when there are heavy freeway demands. The extent to which this is an issue may depend on the volume of unmetered vehicles.
- **Metered priority lane** – has the advantage that all traffic is metered which improves the control of the mainline bottleneck. Priority vehicles still have to wait at the ramp signals, but will experience shorter queues and less delay entering the freeway. The disadvantage of a metered priority lane is that heavy vehicles generally have longer acceleration lengths and so the distances required for acceleration and merge tapers are greater. This may impact on available storage if the stop line needs to be pulled back from the nose and / or result in longer acceleration lengths on the freeway.

Metering can use the same signal cycle for all lanes or the priority lane can have a different cycle time to the other lanes. However; there are possible issues with the latter approach. For example in relation to lantern visibility and potential confusion for drivers (e.g. drivers on the same approach expect to receive the same green time).

**Warrants and approval guidelines**

Priority access at entry ramps using priority lanes is recommended for freight vehicles where it does not adversely impact on the performance of the mainline freeway and where there is sufficient demand on ramps which:

- provide access points from major industrial and commercial areas
- are located along identified freight corridors or routes (e.g. the principal freight network).

Generally, a priority lane is recommended for entry ramps where the peak flow is ≥ 600 veh/h with at least 15% heavy vehicles\(^{21}\). Each traffic lane should be designed to accommodate a maximum of 600 veh/h.

For entry ramps with ramp signals, the requirement for a metered or free-flowing lane should be determined on a case-by-case basis and is dependent on the control needed to manage downstream bottlenecks. Due consideration should also be given to the ramp and freeway geometry and required acceleration and merge distances.

It is recommended that uncontrolled free flow by pass lanes are only used when detailed analysis demonstrates there are no critical bottlenecks within three to four downstream sections of the freeway. The location of other free flow priority lanes may also need to be considered to ensure adequate control of mainline flow can be achieved.

Note: Metering heavy vehicle priority lanes with greater than 4% incline may be difficult to achieve without significantly impacting on operational performance. For some entry ramps it may be possible to address concerns through geometric design e.g. provision of longer acceleration distances. Operation of the current ramp signals in Melbourne installed over recent years has demonstrated that the acceleration standards have operated satisfactorily, including for trucks.

Consideration should also be given to provisions for other high-value traffic such as public transport (i.e. on bus priority routes), taxis, high-occupancy vehicles and low-emission vehicles, as well as management of ramp signalling strategies for emergency vehicle access.

Specific measures to provide priority for emergency vehicles in the vicinity of hospitals and fire departments may be required.

Main Roads’ policy is not to provide any mid-block priority lanes for high-value vehicles, as they adversely affect the overall productivity of the freeway.

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\(^{21}\) This warrant should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes.
Note: Main Roads’ policy in relation to priority facilities for high-value vehicles will be further developed in coordination with the Department of Transport and made consistent with government policy objectives. This will include further guidance on the use of free-flow compared to metered priority lanes and may also include consideration of priority egress facilities.

**Technology and installation configurations**

Appropriate measures such as lane markings and fixed signing should be used to demarcate the priority lane at entry ramps for use by priority vehicles and to separate the priority vehicle lane from the general traffic lanes. If metered, the priority lane should be fully integrated with the CRS algorithm. The priority lane may need special consideration in terms of width to accommodate the swept path of larger vehicles.

**Key dependencies**

Priority access is related to the following other MF interventions:

- **Control:** freeway ramp signals (priority lane).
- **Traveller information:** not applicable.
- **Network intelligence:** vehicle detectors and CCTV.

### 5.5 Arterial Road Traffic Signals (SCATS)

In WA traffic signals are operated through SCATS (Sydney Coordinated Adaptive Traffic System). The system provides adaptive timing and coordination of traffic signals. Traffic signals are not deployed on freeway mainline sections (aside from perhaps at the end) but traffic signals at intersections between freeway ramps and arterial roads might be integrated with the freeway operations, particularly in relation to CRS.

**Warrants and approval guidelines**

Adjustments to the traffic signals program to integrate traffic conditions on the freeway and its entry and exit ramps should be considered for the following purposes and locations:

- management of entry ramp queues where the arterial road is used for queue storage, interfacing between coordinated ramp signal algorithm and SCATS
- management of exit ramp queuing that extends back to the freeway i.e. at ramps with high exit volumes
- control traffic flows at the end of freeways, where signalised intersections result in queue build ups on the freeway
- access control onto the freeways in case of ramp and freeway closures.

**Technology and installation configurations**

Additional vehicle detectors should be installed e.g. queue detection at a minimum of two locations at entry ramps, exit ramps and the end of freeways.
Key dependencies

Traffic signals are related to the following other MF interventions:

- **Control**: freeway ramp signals
- **Traveller information**: not applicable.
- **Network intelligence**: vehicle detectors and CCTV.

5.6 Enforcement

The traffic control interventions installed in MF will imply a new driving experience for many motorists. Therefore it is essential that MF provide an intuitive and self-compliant driving environment. A focus on driver education as opposed to enforcement, particularly in the initial period, will facilitate driver acceptance of the new technologies.

However, MF should be designed with consideration for future requirements for enforcement. Possible enforcement measures include red light infringements at ramp signals and control of compliance of mandatory speed limits, and lane closure instructions displayed through VSL and LUS.

A collaborative approach between Main Roads and Western Australian Police (WAPOL) is essential to determine enforcement requirements for MF.

Warrants and approval guidelines

Enforcement should be considered as a last-resort option to improve driver compliance on freeways with control interventions. It is important to design for an intuitive and self-compliant driving environment and encourage compliance through educational efforts.

Nevertheless, design of the freeway should allow for future implementation of field equipment, control systems and other relevant measures (e.g. enforcement stopping bays for heavy vehicle priority lanes) to support enforcement. These devices should align with Main Roads’ and WAPOL’s systems.

Key dependencies

Systems should be interfaced or integrated with the freeway control system as appropriate.
6 TRAVELLER INFORMATION INTERVENTIONS

6.1 Freeway Variable Message Signs

Freeway variable message signs (VMS) are permanent VMS on the mainline for providing real-time, changeable advice to road users. The messages inform road users about the current traffic conditions on the freeway and major intersecting routes. This includes information on travel-time, congestion (i.e. delays), traffic incidents, road works, special events and the weather (if applicable). This enables them to make informed travel decisions and to choose the most efficient route to their destination, which can also assist in reducing congestion.

The provision of en route traveller information assists traffic operators in optimising the operation and safety performance of the road network. By showing appropriate advice to road users about travel conditions, operators can influence route choice, warn road users of unforeseen situations and reduce driver frustration during abnormal conditions.

The VMS on the freeway mainline are generally used as part of incident and event management, and support the operation of LUMS where relevant (Figure 6-1 – left). The default settings of the VMS are to show real-time travel-times and freeway traffic conditions to destinations / interchanges downstream or on intersecting routes (Figure 6-1 – right).

At the approaches to major decision points such as significant exit ramps (e.g. likely to be used for trip diversion) or freeway-to-freeway interchanges, the VMS provide specific traffic condition information for drivers leaving the freeway. For example, travel-times to destinations on the intersecting route (Figure 6-2).

The information content and message hierarchy for the mainline VMS are described in Main Roads’ ‘Guide for Traveller Information Displays on Variable Message Signs for Managed Freeways’ (ARRB 2012c).

Warrants and approval guidelines

All mainline VMS should be deployed in alignment with the ‘Guide for Traveller Information Displays on Variable Message Signs for Managed Freeways’ (ARRB 2012c). Refer specifically to Section 2.5.2 of the latter document for design principles for locating signs.

Note: Main Roads' existing standards for VMS (Main Roads 2011b) will be reviewed for consistency with these guidelines.
Warrants should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes.

**Moderately to heavily trafficked freeways with an AADT equivalent to > 15,000 veh/lane (based on current volumes) and / or Managed Freeways:**

VMS on the mainline that are capable of showing real-time travel-time and other information as described above are recommended at a spacing of typically 3 to 5 km, subject to the spacing of significant interchanges and presence of a LUMS environment.

In particular, VMS signs should typically be provided:

- 900 m to 1,200 m prior to major decision points to provide adequate time for road users to respond; major decision points include:
  - significant exit ramps (peak ramp flow ≥ 1,000 veh/h)\(^{22}\), e.g. where alternative routes are available and they are likely to be used for trip diversion
  - freeway-to-freeway interchanges
- prior to a LUMS environment to advise of lane closures or reduced speed limits.

They should be located at appropriate locations on the mainline freeway such that the messages displayed are relevant to a significant proportion of the freeway road users passing the sign. The location of the sign also needs to be consistent with incident management plans.

**Lightly to moderately trafficked freeways with an AADT equivalent to < 15,000 veh/lane (based on current volumes), i.e. foundation level ITS:**

It is recommended that a foundation level of roadside traveller information be provided on all freeways. As a minimum, consideration should be given to the installation of VMS in advance of major decision points (including significant exit ramps and freeway-to-freeway interchanges as detailed above) and key bottleneck or incident locations. A recommended spacing for mainline VMS is 5 to 10 km.

The positioning of VMS should be designed to facilitate retrofitting of MF control interventions and requirements for enhanced real-time information (e.g. 3 to 5 km spacing).

**Technology and Installation Configurations**

The freeway VMS technology and installation configurations must be aligned with the recommendations of the ‘Guide for Traveller Information Displays on Variable Message Signs for Managed Freeways’ (ARRB 2012c). Refer specifically to Section 2.1 of this document for guidance on technology, Section 2.5.2 for guidance on design principles for locating signs and Section 2.5.3 for guidance on installation (i.e. use of gantry-mounted or side-mounted cantilever signs). Further guidance is also provided in VicRoads’ ‘Managed Freeways handbook for LUMS, VSL and traveller information’ (2012).

As a general principle, VMS need to be multi-purpose rather than single-purpose and the number of different VMS types limited to a minimum for reasons of system and maintenance management. VMS should be able to display incident warnings as well as real-time traffic information and travel-time information (ARRB 2012c).

\(^{22}\) Warrants should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes.
Messages displaying real-time travel-times and traffic conditions for freeways and intersecting routes can only be displayed on the VMS if timely and accurate traffic data is available for the relevant freeway or arterial road. Guidance on travel-time tracking and associated data for the arterial road network is provided in Section 7.5 and Section 7.3 respectively.

Where located on sections of road with LUMS in place, the VMS should be integrated with the system to provide consistent messaging.

**Key dependencies**

Freeway VMS are related to the following other MF interventions:

- **Control**: freeway ramp signals, VSL, LUMS.
- **Traveller information**: arterial road VMS.
- **Network intelligence**: vehicle detectors and travel-time calculations.

### 6.2 Arterial Road Variable Message Signs

Arterial road VMS – also referred to as real-time information signs (RTIS) or RC3 in relation to CRS – are used to provide advance warning and information on freeway traffic conditions to road users before they enter the freeway. This includes travel-time information as well as integrated messages associated with freeway traffic conditions i.e., level of congestion, incidents, road works and freeway closures. The signs can be located on the approaches to the freeway interchange, prior to the left-turn and right-turn lanes or at other strategic locations on the arterial road network, where route choice of traffic approaching the freeway can be influenced (Figure 6-3). The latter signs are also referred to as advanced RTIS and these signs can assist in diverting traffic away from the freeway when it is congested or during an incident.

Both types of arterial road VMS will show as default the travel-times or freeway traffic conditions for two travel destinations. At interchanges close to a downstream fork or freeway-to-freeway interchange, where road users may travel in different directions, four key destinations (two destinations per route) can be provided by using two signs at each location.

![Figure 6-3: Examples of arterial road VMS (or RTIS)](source: ARRB (2012c).)
Warrants and approval guidelines

All mainline VMS should be deployed in alignment with the ‘Guide for Traveller Information Displays on Variable Message Signs for Managed Freeways’ (ARRB 2012c). 

Note: Main Roads’ existing standards for VMS (Main Roads 2011b) will be reviewed for consistency with these guidelines.

Warrants should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes.

Moderately to heavily trafficked freeways with an AADT equivalent to > 15,000 veh/lane (based on current volumes) and / or Managed Freeways:

RC3 signs should be installed on the approaches to freeway interchanges where ramp signals are provided (refer to Section 5.1 for further detail and Section 3.2.3 of ARRB 2012c). Separate signs should be installed for all turning movements.

In addition, it is recommended that RC3 signs are installed at unmetered ramps with a high traffic movement from the arterial road to the freeway (peak hour ramp flow ≥ 600 veh/h)23. Signs may not be required where a very low traffic movement turns onto the freeway ramp or where the entry point is near the end of the freeway and there is minimum benefit in providing traveller information.

Consider deployment of arterial road VMS in remote locations (i.e. prior to the road user committing to the freeway) in advance of major arterial route intersections where there is an alternative ‘parallel’ route available, which can provide travel to similar significant end-destinations when compared with travel on the freeway.

Lightly to moderately trafficked freeways with an AADT equivalent to < 15,000 veh/lane (based on current volumes), i.e. foundation level ITS:

As a minimum, consideration should be given to the installation of RC3 signs at ramps with a high traffic movement from the arterial road to the freeway (peak hour ramp flow ≥ 600 veh/h)23.

The positioning of arterial road VMS should be designed to facilitate retrofitting of MF control interventions (e.g. consider positioning of RC3 and communications units at entry ramps) (VicRoads 2010b).

Technology and installation configurations

VMS technology and installation configurations must be aligned with the recommendations of the ‘Guide for Traveller Information Displays on Variable Message Signs for Managed Freeways’ (ARRB 2012c). Refer specifically to Section 3.1 of this document for guidance on technology and Section 3.2.3 for guidance on design principles for locating arterial road VMS. Further guidance is also provided in VicRoads’ ‘Managed Freeways handbook for LUMS, VSL and traveller information’ (2012).

Further guidance provided in Section 6.1 in relation to technology and installation configurations for freeway VMS also apply to arterial road VMS.

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23 Warrants should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes.
Key dependencies

Arterial road VMS are related to the following other MF interventions:

- **Control**: freeway ramp signals, VSL and LUMS.
- **Traveller information**: freeway VMS.
- **Network intelligence**: vehicle detectors, travel-time calculations and arterial road traffic data.

6.3 Public Transport Variable Message Signs

VMS can be used to display information on public transport services. The information allows road users to make a well-considered decision on mode choice and stimulates public transport use in congested situations.

The information displayed on the signs could include:

- travel-time to a destination (e.g. Perth CBD) by train
- time until next (and following) train departs or frequency of departing trains
- number of parking spaces available at railway station car park.

Warrants and approval guidelines

VMS that display real-time public transport information to assist with driver route choice are not critical for MF operations, however could be considered at locations where public transport is a feasible alternative. For example, along the Kwinana Freeway and Mitchell Freeway where there are train services, including stations and parking, along the medians.

At this stage, roadside traveller information strategies should focus on road-based information with the potential to include public transport information in an expanded strategy at a later date.

Technology and installation configurations

Public transport information should be displayed on separate VMS to freeway VMS (Section 6.1) and arterial road VMS (Section 6.2), which display road and traffic information, to avoid confusion. The type of signs used to display the public transport information should be similar to the freeway and arterial road VMS to provide consistency in the technology installed on the network.

Key dependencies

Public transport VMS are related to the following other MF interventions:

- **Control**: not applicable.
- **Traveller information**: not applicable.
- **Network intelligence**: not applicable.

6.4 Advance Warning Flashing Signals

Advance warning flashing signals are used in various situations to attract attention to a specific hazard, which may be unexpected, or of higher than normal potential risk. The intention is to provide drivers with additional information to enable them to react more readily and thereby avoid or reduce the risks. The signals can take the form of a single flashing display or, more
conventionally, twin alternating displays. They may be installed by themselves, in conjunction with a fixed traffic sign, or as an integral part of a warning sign.

The electronic components can be activated at set times or occasions (e.g. when traffic signals are red) or can be activated by a threshold triggered by a passing vehicle (e.g. speed on the approach to a sharp curve or vehicle height on approach to a low clearance site). If vehicle activated warning signs are used, the systems incorporate vehicle detection to detect passing vehicles and activate the threshold trigger that displays the warning signals. With this system, the signals can be activated for the drivers that require a warning only (e.g. high-speed vehicles on the approach to a sharp curve or over-height vehicles on approach to a low clearance site). The fixed part of the sign provides advice on appropriate corrective action (e.g. take the next exit).

**Warrants and approval guidelines**

Advance warning flashing signals should be deployed in accordance with the relevant standard 67-08-1 (Main Roads 2012b).

Advance warning flashing signals should be considered for installation on freeways on the approaches to hazardous locations. This includes the following locations on the mainline freeway or entry and exit ramps:

- at steep descents
- at sharp curves
- at large speed drops
- in advance of traffic signals at the end of freeways
- in advance of ramp signals on the freeway-to-freeway interchange
- in advance of low clearance sites such as tunnels and bridges (with over-height detection).

The installation of over-height vehicle detection and warning systems on the principal freight network is highly recommended and should have priority.

**Technology and installation configurations**

Advance warning flashing signals should be installed in accordance with the relevant standard 67-08-1 (Main Roads 2012).

**Key dependencies**

Advance warning flashing signals are related to the following other MF interventions:

- **Control**: not applicable.
- **Traveller information**: not applicable.
- **Network intelligence**: not applicable.

### 6.5 Pre-trip and In-car Traveller Information

In addition to roadside signage, there are a number of pre-trip and in-car measures that can be utilised to provide traveller information and assist traffic operators with managing traffic on the network. These include Main Roads’ website, social media, radio, TV, smart-phone applications and satellite navigation systems.
Warrants and approval guidelines

Main Roads uses a variety of systems and processes to provide these services on a network-wide basis. There are no specific requirements for the development of additional systems and processes to support MF. However, existing services should be utilised for maximum effectiveness in assisting with traffic management. For example, the timely provision of information on incidents or congestion affecting the network will support alternative route choices and help to improve safety for road users within the affected freeway section.

Examples of ITS devices that may be deployed on the network to support provision of pre-trip and in-car traveller information include:

- **WebCams** – fixed CCTV cameras used for the sole purpose of live streaming videos of the network on Main Roads’ website for public viewing. They are not used for traffic management purposes.
- **Vehicle detectors** – traffic data from vehicle detectors are used for graphical maps displaying real-time travel conditions such as average speeds and congestion on the network that is accessed via Main Roads’ website. These maps can also display incident and event data, and assist travellers in their route and mode choice decisions.

Technology and installation configurations

The key consideration for MF design is the requirement to install web cameras at strategic locations along the freeway. The required specifications for these CCTV cameras might differ from the specifications for CCTV cameras used for traffic management, for example the PTZ function is not required and lower resolution may be appropriate.

Key dependencies

Systems should be interfaced or integrated with the freeway control system as appropriate.

6.6 Fixed Signage

Within an MF environment, additional fixed signage can alert and educate drivers on the change in the operational conditions. These signs can provide general instructions or information on MF or could provide assistance for a specific control intervention. The main purpose of the signs is to improve driver acceptance and compliance, and thus enhance the safety of the freeway.

Warrants and approval guidelines

MF should be designed to provide intuitive and self-compliant driving environments. Nevertheless they will be a new experience for many WA drivers and, as such, it may be necessary to provide additional fixed signs to the standard requirements for freeways to help improve safety and driver awareness and compliance, particularly in the initial stages of MF deployment. The types of fixed signs that could be considered include:

- Gateway signs located upstream of the MF section, including at entry ramps, to inform road users on entering an MF with special characteristics (e.g. no emergency lane or CRS in operation).
- Signs located within the MF section to reinforce safety critical information (e.g. distance to emergency stopping bay / safe stopping location when an emergency lane is not present).
- Signs at specific locations providing instructions for specific interventions (e.g. CRS are in operation, refer to Section 5.1, or default speed limit in VSL zones).
Technology and installation configurations

The additional types of fixed signs should be considered alongside the standard requirements for fixed signage at freeways. They should be integrated within the wider strategy for provision of information to the road user at a network-wide level, including on-road signage (fixed and electronic signs) and pre-trip and in-car information. In some situations a departure from the existing standards for fixed signs on freeways may be required to accommodate integration of MF fixed signs, for example speed limit signs on sections where VSL are in operation.

The managed freeway fixed signs should not be located in the vicinity of driver decision points, where they have the potential to distract from the driving task. The signs should also be consistent with messages communicated via MF public education programs.

Key dependencies

Not applicable.
7 NETWORK INTELLIGENCE INTERVENTIONS

7.1 Vehicle Detectors

Vehicle detectors are used to collect real-time traffic data. This includes volume, speed, occupancy (density) and vehicle classifications on a lane-by-lane basis. The real-time data is the basis for monitoring and control of the freeway, for example vehicle detector data is the primary input for CRS algorithms, operation of VSL signs, some travel-time calculation algorithms and some automated incident detection systems.

The real-time data can also be used for traveller information. For example, to display freeway conditions such as travel-times, average speeds and congestion levels on VMS. It is also provided to third parties for incorporation in commercial applications such as satellite navigation systems.

Historic data from the vehicle detectors is archived and used for freeway performance monitoring, evaluation and reporting.

Warrants and approval guidelines

Moderately to heavily trafficked freeways with an AADT equivalent to > 15,000 veh/lane (based on current volumes) and / or Managed Freeways:

Vehicle detectors should be installed at all lanes, including the emergency lane if it is used as a permanent or part-time running lane. Detectors should at least be installed on the following locations, with additional sensors at a maximum spacing of 500 m:

- upstream of the nose of all entry ramps, with detectors for ramp and mainline traffic
- downstream of the nose of all exit ramps, with detectors for ramp and mainline traffic
- at the end of all entry ramp merges (primary mainline sites for coordinated ramp signals)
- potential bottleneck locations, e.g. downstream of lane drops, on steep upgrades, tight curves, speed changes or road narrowing such as bridges and tunnels
- at two or more locations on the entry ramps, to measure queue lengths of the ramp signals
- at two or more locations on the exit ramps, to measure queue lengths
- within emergency stopping bays (e.g. at entry and ‘parking areas’).

Where arterial roads are to be used for ramp storage, vehicle detectors will also be required in the ramp storage area pertaining to the arterial road.

Refer to Section 5.1.1 for further detail on the requirements for vehicle detectors to support freeway ramp signal operations.

Lightly to moderately trafficked freeways with an AADT equivalent to < 15,000 veh/lane (based on current volumes), i.e. foundation level ITS:

Vehicle detectors on the mainline should be installed at all lanes, including the emergency lane if it is used as a permanent or part-time running lane. On lightly to moderately trafficked freeways, a spacing of 500 m up to a maximum of 2 km on the mainline should be applied as appropriate.

Note: For lightly to moderately trafficked freeways, which are likely to be unmanaged (i.e. with foundation level of ITS only), a greater spacing will still provide a useful level of performance.

Note: This design feature is not currently incorporated to the Managed Freeways Pilot Project design and may not be supported in the control system procured by Main Roads.
monitoring and travel-time tracking to support the provision of traveller information, but at a reduced cost considering that costs for ongoing operations and maintenance are incurred from installation.

On lightly to moderately trafficked freeways, detectors should be installed at the following locations on the mainline:

- upstream of the nose of all entry ramps
- downstream of the nose of all exit ramps
- potential bottleneck locations, e.g. downstream of lane drops, on steep upgrades, tight curves or road narrowing such as bridges and tunnels.

Detectors should also be installed on all entry ramps and exit ramps for traffic counting purposes, historical analysis of data and consideration of future proposals, e.g. to provide data when planning for CRS, where it is preferred to use actual ramp counts then volume calculations based on upstream and downstream detectors.

Note: The warrants above necessitate a variation from the application and approval guidelines outlined in the existing Main Roads’ standard 67-08-71 (2011b). This standard will be reviewed for consistency with these guidelines.

Technology and installation configurations

Vehicle detectors commonly consist of wireless magnetic field sensors or loop-based sensors that are embedded in the road surface. Both sensor types are currently used on Main Roads’ freeway network.

Other technologies which are mounted on the roadside are non-intrusive, e.g. radar detectors and video-based systems. Main Roads does not currently use these technologies for network monitoring except TIRTL (The Infra-Red Traffic Logger) being used as permanent traffic counters at network performance sites.

As real-time data is critical to MF operations, factors to be considered in selecting a suitable detection technology include:

- suitability of data for the required uses (i.e. type and quality)
- availability of data (i.e. reliability and repair)
- whole-of-life costs (including traffic management).

The specific locations of detectors depend on many factors including requirements for traffic management, presence of interchanges, road geometry and operational requirements.

Vehicle detectors installed on freeway sections with a foundation level of ITS should be located as appropriate to facilitate cost-effective retrofitting of MF interventions that are likely to be deployed on that section. For example, at appropriate locations for freeway ramp signalling and detector spacing of 500 m on the mainline (refer to Section 5.1.1). Design should also consider requirements for freeway performance evaluation for operational performance tuning and strategic reporting.

Key dependencies

The vehicle detectors are related to the following other MF interventions:

- **Control**: ramp signals, LUMS, VSL, priority vehicle facilities.
Managed Freeways Provision Guidelines

- **Traveller information**: VMS and pre-trip and in-car traveller information.
- **Network intelligence**: arterial road traffic data, AIDS and travel-time tracking.

### 7.2 Closed Circuit Television Cameras

Closed circuit television (CCTV) cameras are used for surveillance of the network, particularly for managing unusual conditions. They provide vision of the real-time traffic conditions and activities on the road network, and primarily assist the traffic operators with verifying and managing traffic congestion, incidents, road works and other planned events.

CCTV is also essential for monitoring the ramp signals’ operations, including day-to-day monitoring of ramp queues, driver behaviour and identification of operational issues as well as fine-tuning of the algorithm. In the course of operation of the emergency lane as a running lane CCTV is crucial for surveillance of the emergency lane before and during operation of the lane (Section 5.3.2). The cameras might also be used to provide verification of information displayed on roadside electronic signs and signals.

CCTV on the arterial road network can assist in the assessment of queue lengths and conditions on the approach routes to the freeway and support the operation of control interventions such as coordinated ramp signalling.

The CCTV images are constantly monitored by the traffic operators in the traffic operations centre (TOC) and may also be shared with external stakeholders for incident and emergency management (e.g. the police) and public transport management (e.g. PTA).

**Warrants and approval guidelines**

**Moderately to heavily trafficked freeways with an AADT equivalent to > 15,000 veh/lane (based on current volumes) and / or Managed Freeways:**

CCTV cameras should be installed to provide full and unobstructed coverage of both carriageways of the freeway. Full coverage will include:

- all interchanges
- full length of entry ramps with ramp signals
- intersections to entry ramps with ramp signals
- emergency lanes and emergency stopping bays
- typically 1000 m spacing on straight road sections, depending on height, technology and visibility
- closer spacing at curved alignments, underpasses and visibility restricted areas.

Overlapping coverage should also be considered at key bottleneck and incident locations. The TOC should be consulted on suitable locations. Overlapping coverage, as shown in Figure 7-1, provides the following benefits:

- no need to change position of the CCTV camera to have full coverage of the network
- viewing and observation of incidents from two directions
- use of separate cameras for simultaneous incident management and observation of traffic operation upstream of the incident
- allowance for redundancy (e.g. malfunctioning).
Figure 7-1: Full (blue) and overlapping (blue and red) coverage of CCTV cameras on a freeway

Lightly to moderately trafficked freeways with an AADT equivalent to < 15,000 veh/lane (based on current volumes), i.e. foundation level ITS:

CCTV cameras should be installed at all interchanges and key bottlenecks (i.e. sections experiencing recurrent congestion) and incident locations.

All freeways:

If verification of VMS messages is not provided by other means (e.g. via the central control system), consideration should also be given to the location of CCTV to provide full visibility of roadside electronic signs and signal displays. This should take into account cost implications and be undertaken in consultation with the TOC to understand operational requirements.

Note: The warrants above necessitate a variation from the application and approval guidelines outlined in the existing Main Roads’ Standard 67-08-71 (Main Roads 2011b). This standard will be reviewed for consistency with these guidelines.

Technology and installation configurations

Full pan, tilt and zoom (PTZ) cameras, with IP-based digital technology and day-time and night-time operating modes as well as video recording capabilities are required. The cameras should be mounted on dedicated poles or other existing facilities (e.g. lighting columns or gantries). Tilting poles could be considered as they have great maintenance benefits, however are more expensive.

The camera locations need to be designed to maximise the coverage by considering:

- horizontal and vertical alignment
- visibility-obscured sight lines, e.g. by bridges, signage, gantries, trees.

CCTV installed on freeway sections with a foundation level of ITS should be located as appropriate to facilitate cost-effective upgrade to enhanced levels of provision for MF i.e. 1,000 m – 2, 000 m spacing on the mainline.

Key dependencies

CCTV is related to the following other MF interventions:

- **Control**: ramp signals, LUMS when used for part-time ELR, ALR and reversible lane systems (for verification during dynamic lane use).
- **Traveller information**: not applicable.
- **Network intelligence**: AIDS and travel-time calculations.
7.3 Arterial Road Traffic Data (SCATS Data)

MF should be implemented as part of a whole-of-network operations approach and to enhance overall journey times across the arterial and freeway road network. Data on the arterial road traffic conditions assists traffic operators in the optimal operation of control interventions on the freeway. Arterial road traffic data is also used for traveller information for freeway users, e.g. traffic conditions, travel-times and average travel speeds. Arterial road traffic data is acquired through vehicle detectors at traffic lights and mid-block sections, with additional intelligence provided to traffic operators via CCTV.

**Warrants and approval guidelines**

Real-time traffic data may be required for the arterial road network in the vicinity of the freeway, particularly on connecting and parallel routes, and intersections between freeway ramps and arterial roads.

A review should be undertaken to determine whether the existing arterial traffic data is sufficient to support MF operations. Gaps in the provision of arterial traffic data may require installation of additional field equipment.

**Managed Freeways with ramp signals:**

Where arterial roads are used for ramp storage, vehicle detectors will be required in the ramp storage area pertaining to the arterial road.

**Technology and installation configurations**

Installation of devices should align with relevant requirements outlined in Section 5.1 (CRS), Section 7.1 (vehicle detectors) and Section 7.2 (CCTV).

**Key dependencies**

Arterial road traffic data procurement is related to the following other MF interventions:

- **Control:** ramp signals.
- **Traveller information:** VMS, pre-trip and in-car traveller information.
- **Network intelligence:** vehicle detectors, CCTV and travel-time tracking.

7.4 Emergency Telephones

Emergency telephones facilitate road user safety and security by providing a ready means of communication to Main Roads in the event of a breakdown, crash, or other incident, for which assistance is required.

Emergency telephones support incident detection and response and thereby contribute to increased freeway efficiency and safety. For example, by reducing the risk of further incidents by facilitating the prompt removal of disabled vehicles and other hazards from the carriageway.

Calls from emergency telephones are identified as priority calls through the Customer Information Centres (CIC). The CIC will alert relevant internal stakeholders, including traffic operators, as well as the emergency services and towing services as required.
Warrants and approval guidelines

Emergency telephones must be provided on all freeways as per Main Roads' ‘Emergency Telephone Guidelines’ on the website.

Freeways with ALR or part-time ELR:

Where operational strategies are implemented to enable dynamic full pavement utilisation, and the emergency lane is used as a running lane on a part-time or full-time basis, emergency telephones should only be provided in emergency stopping bays and not adjacent to the carriageway.

Note: The existing guidelines for emergency telephones (as of June 2012) will be reviewed to identify any changes in requirements for MF. For example, there may be potential for increased spacing on MF sections due to enhanced network surveillance and monitoring (e.g. via vehicle detectors, CCTV and AIS) as well as a result of increased mobile phone usage and possible future deployment of on-road teams that will improve network surveillance and incident management. This may achieve cost savings but should be carefully considered in terms of the implications for road safety. Further guidance will be provided when available.

Technology and Installation Configurations

Refer to Main Roads’ ‘Emergency Telephone Guidelines’ as provided on the website.

Key dependencies

Emergency telephones are related to the following other Managed Freeway interventions:

- **Control**: LUMS when used for part-time ELR and ALR (provision in emergency stopping bays only).
- **Traveller information**: not applicable.
- **Network intelligence**: not applicable.

7.5 Travel-Time Calculation

Tracking vehicle movements is useful for travel-time calculations to support provision of real-time traveller information, including pre-trip and en-route. It provides an additional data source for monitoring or validating network performance. Individual vehicle travel-time data as acquired via technologies such as automatic number plate recognition (ANPR) and Bluetooth can also be used to assess origin-destination patterns and improve understanding of traffic demand on the freeway and arterial road network.

Warrants and approval guidelines

If VMS are to be provided on freeways and arterial roads for the display of real-time travel-time information as part of MF (Sections 6.1 and 6.2) then travel-time calculations will be required.

Main Roads’ policies for the provision of pre-trip and in-car traveller information should also be reviewed to assess the requirements for travel-time calculations.

Technology and installation configurations

Travel-time calculations can be achieved either through the application of algorithms using traffic speed data (i.e. from vehicle detectors) or via CCTV-based technologies using optical character recognition to capture number plate information (i.e. ANPR). New technologies incorporating in-car
solutions are still in development, for example technologies which use floating car data through GPS, mobile phone networks and vehicle identification tags.

The most effective and reliable approach is to use traffic data from a combination of sources. This requires a coordinated approach for storage, access and integration of the data.

The choice of key routes for travel-time calculations should be consistent with the ‘Guide for Traveller Information Displays on Variable Message Signs for Managed Freeways’ (Section 5 of ARRB 2012c). This source also provides further guidance on the methodology for calculating travel-times from vehicle detector data (Section 4) as well as consideration of possible alternative methodologies such as predictive travel-time (Section 6.1).

Key dependencies

Travel-time tracking is related to the following other MF interventions:

- **Control**: not applicable.
- **Traveller information**: VMS and pre-trip and in-car systems.
- **Network intelligence**: vehicle detectors and CCTV (as well as GPS and other mobile devices).

7.6 Automatic Incident Detection Systems

Automatic incident detection systems (AIDS) enable direct and automatic detection of incidents or irregular traffic flows. They can be used to alert operators of possible incidents through detection of a slow-moving or stationary vehicle, unauthorised pedestrian or animal movements or other objects such as debris. This system can improve safety for freeway users and contribute to increased freeway efficiency by improving the timeliness of incident detection and response.

AIDS may be integrated with control interventions, particularly CRS, VSL and LUMS to trigger (semi-)automated adjustments in traffic control in response to the occurrence of incidents and changing network conditions.

Warrants and approval guidelines

AIDS is recommended for consideration to improve road safety and incident detection and response times, particularly at the following freeway locations:

- bottlenecks
- sections with high incident rates
- sections where there is no or reduced width of the emergency lane (e.g. tunnels, bridges, freeway-to-freeway ramps)
- sections where there is full pavement utilisation and the emergency lane is being used as a running lane on a full-time or part-time basis (e.g. ALR or part-time ELR).

Technology and installation configurations

AIDS can consist of a video image processing system with motion detection technologies (i.e. based on CCTV) or algorithms using traffic speed, flow and direction data (i.e. from vehicle detectors). The system should cover all running lanes, including the emergency lane, if it is used as a running lane on either a permanent or part-time basis (refer to Section 5.3.1 and 5.3.2).
The technology should include both day-time and night-time operational modes, which might require additional lighting facilities on the freeway when CCTV cameras are used. CCTV cameras and vehicle detectors used for surveillance, monitoring and traffic data provision can also be used for AIDS. However, at some locations, additional field equipment might be required to ensure complete coverage, e.g. when cameras are often repositioned for surveillance purposes.

**Key dependencies**

AIDS is related to the following other MF interventions:

- **Control**: ramp signals, VSL, LUMS (when used for part-time ELR and ALR).
- **Traveller information**: VMS and pre-trip and in-car systems.
- **Network intelligence**: vehicle detectors and CCTV.

### 7.7 Communications and Data Sharing with Internal and External Stakeholders

An important source of intelligence for network operations is information acquired from various stakeholders, including:

- external stakeholders, for example Western Australia Police (WAPOL), the Public Transport Authority (PTA), media and the public
- internal stakeholders, for example the Customer Information Centre and on-road teams consisting of officers and vehicles that patrol the network for surveillance purposes, provide rapid on-scene response during incidents or conduct maintenance activities.

Video sharing also takes place between Main Roads and other stakeholders including WAPOL and PTA. The VidiWall has been configured to enable display of images from both Main Roads’ and PTA’s CCTV cameras.

**Warrants and approval guidelines**

Main Roads has a variety of information and communication technology (ICT) systems and processes in place to facilitate communications and data exchange with stakeholders in support of network operations. It is not anticipated that there is a need for the deployment of equipment or operating systems specifically for MF. However, existing and new ICT systems should be suitable for integration with MF operations. There may also be requirements for integration between control systems of Main Roads and other jurisdictions, for example to facilitate sharing of CCTV images.

**Key dependencies**

There may be no dependencies with other MF interventions however ICT systems should be integrated with the freeway control system as appropriate.

### 7.8 Environmental Monitoring

Environmental monitoring incorporates systems that monitor environmental conditions on and around the road network, such as water levels, temperature, wind speed, precipitation and visibility. The monitoring equipment can activate appropriate equipment to respond to changing conditions (e.g. drainage pumps) or warn road users of adverse conditions and possible hazards (e.g. via roadside electronic signage).

There are interstate and international examples of the use of environmental triggers for operation of control interventions such as VSL. For example, display of reduced speed limits during heavy
rainfall or high wind speeds to improve safety. There is also developing, but still limited, use of emissions and noise triggers for VSL operation in Europe to assist in compliance with environmental regulations.

**Warrants and approval guidelines**

Given the breadth of applications, limited general guidance is available for environmental monitoring and warning systems, and provision needs to be on the basis of benefits and costs of individual proposals.

Installation of environmental monitoring systems might be considered at certain locations to provide warning to motorists about specific adverse weather conditions that commonly affect travel on that part of the network. Network intelligence interventions such as vehicle detectors and CCTV can be used to identify and verify adverse weather events affecting traffic flows on the network. Appropriate traveller information can then be displayed by VMS to help manage traffic flows. Environmental monitoring systems could also be used to trigger automated speed control.

Main Roads is currently using flood-monitoring sensors in remote regions on a trial basis to activate warning signs and inform of lane closures during flood conditions (Note - This is not an MF application).

**Key dependencies**

Environmental monitoring is related to the following other MF interventions:

- **Control:** VSL.
- **Traveller information:** VMS, pre-trip and in-car systems.
- **Network intelligence:** CCTV.
8  FOUNDATION INFRASTRUCTURE

8.1  Communication Network

Communications underpin ITS as is the case with other information technology. Communications between devices at ITS sites, the server and operation room at the Traffic Operations Centre allow the transfer of data, and provide the ability to monitor and control these devices remotely.

With increasing density of ITS assets in freeway corridors as well as building towards MF, it becomes increasingly beneficial to have high-quality communications such as fibre optic cable available within the freeway corridor. High-capacity communications infrastructure is also a key enabler for future vehicle-infrastructure integration initiatives which enable communication between vehicles and roadside infrastructure.

The key considerations for Managed Freeway design and communications infrastructure are:

- **Capacity (i.e. bandwidth)** – to accommodate additional ITS assets including planned projects and future upgrades.
- **Resilience (including redundancy)** – to ensure that there is no single point of failure in communications between field equipment and the TOC.
- **Security** – in terms of access to data and hardware.
- **Latency** – to ensure timely exchange of data for real-time (or near real-time) network management.
- **Monitoring and fault management** – to ensure there are appropriate systems in place to minimise the occurrence and impact of communication faults. It is proposed that this will be undertaken through a Network Operations Centre (NOC), a real-time monitoring and automatic alarm system for all switches of electrical infrastructure across the Traffic Control System Network (TCSN). The alarms will be monitored 24/7 by Main Roads or a sub-contractor.

Development of the communications network should also consider future requirements for cooperative ITS (e.g. vehicle-to-vehicle and vehicle-to-infrastructure / infrastructure-to-vehicle communications).

8.2  Power Network

A reliable power supply is necessary for the successful operation of ITS. Similar to communications, the increasing density of ITS assets in freeway corridors means that power supply should be considered on the basis of the freeway corridor in addition to the option of individual connections.

The key considerations are:

- **Capacity** – to provide sufficient power for ITS assets including planned projects and future upgrades.
- **Resilience (including back-up power / uninterruptable power supplies)** – for ITS (field) equipment and equipment / hardware in the TOC to prevent equipment failure which may have road safety implications.
- **Monitoring and fault management** – to ensure there are appropriate systems in place to minimise the occurrence and impact of power faults. Refer to NOC in Section 8.1.
8.3 Traffic Operations Centre

The Traffic Operations Centre (TOC) provides the hub for traffic operations across Main Roads’ network and incorporates the central hardware and control systems for management of ITS field equipment. It is also Main Roads’ central point for coordination and management of incidents and events.

For MF operations, the TOC needs upgrading to provide improved capacity, functionality and / or performance to meet all operational requirements. This includes enhancing the capabilities and resources required for ongoing management and optimisation of Managed Freeway facilities.

Information sharing with other agencies (e.g. CCTV with Police and PTA) and co-location of other agency personnel at TOC (e.g. Police, other emergency services, media and real-time traveller information providers) will also need to be considered.

8.4 Managed Freeways Control System

WA’s ITS equipment deployed in MF sections needs to be managed by a single control system (i.e. software). This system should provide an operator interface for all of the various sub-systems and field equipment that deliver MF functions. Ideally, the same control system should be utilised for all network operations activities and ITS interventions deployed on Main Roads’ network, including freeways, arterial and regional networks. This will provide the integration required for efficient and effective management of traffic across the network.

As Main Roads’ MF policy is implemented, the number of interventions deployed on the freeway network along with their interdependencies will increase. An integrated software platform with an open and service orientated architecture will be required to best accommodate this and provide flexibility for future software and technology developments.

8.5 Freeway Performance Evaluation

Freeway performance must be measured for operational performance tuning and strategic reporting. Historical traffic and other network data must be archived and accessible to relevant stakeholders. Traffic data can be acquired from vehicle detectors as well as by devices deployed by the Asset and Network Information team, including permanent count stations and short-term counts / surveys. MF design should consider requirements for project performance evaluation as well as ongoing network performance evaluation.

8.6 System Performance Management

All aspects of a Managed Freeway should operate in a manner that ensures high reliability (i.e. >99% availability) and integrity of the system. To achieve this, the power and communications infrastructure, central control system and equipment in the field and at the TOC should be designed to minimise faults occurring and have automated fault detection and reporting / alarms that minimise fault detection resolution times.

Fault rectification needs to meet tight intervention levels. Therefore, maintenance contracts should ensure that faults critical to the safety or performance of the network, such as LUMS (safety critical) and vehicle detectors (performance critical), are identified and repaired within short timeframes.

8.7 Other Considerations

The following sub-sections provide further guidance on other considerations for deploying ITS and technology interventions as part of MF.
8.7.1 Geometric Modifications
Consideration should also be given to the site-specific geometric road design needed to support the retrofitting of MF, particularly in relation to control interventions that are likely to be considered for future implementation on the freeway section, if it is cost-effective to do so. For example, consider ramp layouts and design requirements for future installation of ramp signals and the design implications of future deployment of cantilever or gantry structures for lane use and speed management.

8.7.2 On-Road Teams
On-road teams consisting of officers and vehicles that patrol the network for surveillance purposes, as well as to provide rapid on-scene response in the event of an incident, as required.

On-road teams that facilitate rapid incident detection and response may be considered a critical service for MF operations on sections where the emergency lane is used as a running lane or for sections of the network with limited capacity overflow. The level of resources required for peak and off-peak times needs to be considered. This depends on expected incident rates, number and location of vulnerable sections of the network and type of MF interventions installed.

Note: Main Roads is currently developing a policy for deployment of on-road teams (as of June 2012). Further guidance will be provided as appropriate.

8.7.3 Lighting
There may be specific MF interventions where lighting is required to improve road user safety and security or to assist with network surveillance.

Note: Main Roads will review existing lighting standards (as of June 2012) to identify if there are any further requirements for MF operations and considering any changes to the road geometry.

8.7.4 Integration with Other ITS and Technologies
ITS and technology-based interventions may be deployed on a section of the freeway for other purposes, e.g. weigh-in-motion data collection to assist asset management and heavy vehicle regulation and network performance sites (i.e. for permanent or short-term traffic counts) that are used for reporting against national performance indicators and other purposes. MF design should consider all ITS interventions to ensure that the required foundation infrastructure is sufficient and to facilitate system and technology integration where appropriate. Refer to existing Main Roads’ standards and guidance as appropriate.
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VicRoads 2010b, Managed freeways: freeway ramp signals handbook, VicRoads, Kew, VIC. [Or refer to latest version as released]

VicRoads 2012 (April), ‘Managed Freeways Handbook: Lane use management, variable speed limits, traveller information’ (revised draft), VicRoads, Kew, VIC. [Or refer to latest version as released]
ADDITIONAL SOURCES


Austroads 2009b, Best practice for variable speed limits: best practice recommendations, AP-R344/09, Austroads, Sydney, NSW.


Note: Various technical standards and guidance documents from Main Roads Western Australia as well as from the UK and Dutch state road agencies were also used.
ABBREVIATIONS

ALR    All lane running
AADT   Annual average daily traffic
AAWT   Annual average weekly traffic
ANPR   Automatic number plate recognition
AIDS   Automatic incident detection system
CCTV   Closed circuit television
CIC    Customer Information Centre
ELR    Emergency lane running
ESL    Emergency Stopping Lane
GPS    Global positioning system
ICT    Information and communications technology
ITS    Intelligent transport systems
LUMS   Lane use management system
LUS    Lane use signs
MF     Managed Freeways
NOC    Network operations centre
PTA    Public Transport Authority
PTZ    Pan, tilt and zoom
RTMT   Real-time monitoring team
SCATS  Sydney Coordinated Adaptive Traffic System
TCSN   Traffic control system network
TIRTL  The Infra-Red Traffic Logger
TOC    Traffic Operations Centre
VMS    Variable message signs
VSL    Variable speed limits
WA     Western Australia
WAPOL  Western Australia Police
WIM    Weigh-in-motion
Appendix A: Requirements for Foundation Level of ITS on Freeways

Foundation level of ITS on freeways

Applicable to lightly to moderately trafficked sections where annual average daily traffic volumes (AADT) are up to 15,000 veh/lane (based on current volumes). Minimum requirements for ITS deployment on freeways. Intervention warrants should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes.

Table A.1: Summary of warrants and approval guidelines for foundation level of ITS

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<th>Intervention</th>
<th>Warrants and approval guidelines</th>
<th>Section</th>
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| Freeway VMS                           | ▪ Consider deployment at spacing of typically 5 km to 10 km on mainline, subject to spacing of significant interchanges and presence of key bottleneck and incident locations.  
                                       | ▪ Recommend that priority is given to deployment in advance of major decision points including interchanges with high exit flows (peak ramp flow ≥ 1,000 veh/h) where alternative routes are available and they are likely to be used for trip diversion, and freeway-to-freeway interchanges. | 6.1     |
| Arterial VMS / RTIS                   | ▪ Consider deployment of RC3 signs at ramps with a high traffic movement from the arterial road to the freeway (peak hour ramp flow ≥ 600 veh/h).                                                                                       | 6.2     |
| Vehicle detectors                     | ▪ Deploy at spacing from 500 m to 2 km on mainline freeway, at all interchanges (including ramps) and as required for traffic counting to inform historical performance analysis and planning activities.                                           | 7.1     |
| CCTV (for incident verification)      | ▪ Deploy at specific locations where network surveillance is beneficial i.e. interchanges, bottlenecks and sections with high incident rates.                                                                                       | 7.2     |
| Emergency telephones (for incident detection) | ▪ Deploy as per existing Main Roads’ ‘Emergency Telephone Guidelines’ provided on website.                                                                                                                                       | 7.4     |
| Travel-time calculation               | ▪ Required to support provision of real-time travel-time information via roadside VMS or pre-trip and in-car services, as well as freeway performance evaluation.                                                               | 7.5     |
| Power and communications (foundation infrastructure) | ▪ Cabling to service complete length of corridor with adequate capacity for future ITS requirements, which may include MF interventions as well as advanced ITS (i.e. co-operative systems).  
                                       | ▪ Longitudinal electrical and fibre optic conduits are preferred, though in some situations other options may be necessary (i.e. local power supplies, wireless).                  | 8.1 and 8.2 |
|                                       | ▪ Separate pits and ducts for communications and power are desirable, with pits provided at all changes in direction and maximum spacing of 250 m on straight mainline sections (considering maximum spacing of MF ITS field equipment at 500 m), as well as appropriate provision on ramps. |          |
| Other                                 | ▪ Other ITS interventions providing network intelligence and traveller information functions should be deployed in accordance with the guidance provided in this document.                                          | 6 and 7 |
|                                       | ▪ Consider ramp layouts to facilitate future retrofitting of ramp signals.                                                                                                                                                        |          |
Appendix B: Requirements for Managed Freeways

Managed Freeways

Applicable to moderately to heavily trafficked freeway sections where annual average daily traffic (AADT) volumes are 15,000 veh/lane or more (based on current volumes) and/or there is recurrent flow breakdown and congestion. An indicator of recurrent congestion is when average peak period travel speeds for a corridor are approximately 60% or less of the posted speed limit. A combination of ITS interventions and geometric improvements may be required.

Intervention warrants should be applied to the estimated traffic volumes in five years after the expected opening, with a sensitivity check against ten year volumes. The control interventions should be applied to a freeway route where the warrant is met at a critical bottleneck for the route i.e. the warrant may not have to be met across the entire section of the route for the intervention to be applied. In many cases, a route treatment may be necessary to prevent flow breakdown at the critical bottleneck.

<table>
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<tr>
<th>Intervention</th>
<th>Warrants and approval guidelines</th>
<th>Section</th>
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| **Ramp signals**                                  | ▪ Coordinated ramp signals. Including freeway-to-freeway ramp signals, should be considered for deployment as a route treatment where peak hour flows are ≥ 1,800 pc/h/lane (approx. 1,700 veh/h/lane with 10% heavy vehicles)\(^\text{25}\). Coordinated ramp signals are appropriate if:  
  — flow breakdown is occurring at a number of bottlenecks over a length of freeway  
  — flow breakdown occurring at a particular location cannot be addressed by an isolated ramp meter (i.e. result of multiple uncontrolled ramp flows)  
  — flow breakdown is already occurring on the freeway when traffic volumes are ≥ 1,800 pc/h/lane (approx. 1,700 veh/h/lane with 10% heavy vehicles).  
  ▪ Additional upstream and downstream ramps may be required for ramp signalling to ensure effective control of a critical bottleneck and to prevent the bottleneck being displaced downstream.  
  ▪ Isolated ramp signals should also be considered to address localised issues or to complete deployment across a corridor.                                                                                           | 5.1     |
| **Variable speed limits (VSL)**                   | ▪ VSL should be investigated as a route-based treatment to help achieve and sustain operational capacities for Managed Freeways with CRS in operation that are achieving flows ≥ 2,000 pc/h/lane (approx. 1,900 veh/h/lane with 10% heavy vehicles) i.e. flows at or near operational capacities.  
  ▪ VSL should also be considered for incident and event management and queue protection on freeway sections with high rates of speed-related incidents or where there are other safety imperatives (i.e. in tunnel environments). Where overhead lane mounting is provided, LUMS should also be integrated with VSL.                              | 5.2     |
| **Lane use management systems (LUMS)**            | ▪ Deployment of LUMS to enable all lane running (ALR) and part-time emergency lane running (ELR) should be considered as a route-based or localised treatment when required to provide additional physical capacity and it is not practically, economically or politically feasible to undertake significant geometric improvements / civil upgrades. VSL should be integrated with LUMS where appropriate.  
  ▪ ALR / part-time ELR should be considered on Managed Freeway sections if the maximum operational capacity (i.e. 2,200 pc/h/lane (approx. 2,100 veh/h/lane with 10% heavy vehicles)\(^\text{26}\)) is being exceeded for significant periods of the day or there are unacceptable impacts of Managed Freeway on the connecting road network. For example:  
    — if average peak period travel speeds are below 65 km/h are on sections with CRS  
    — ramp delays exceed maximum thresholds of four minutes.  
  ▪ LUMS should also be considered for specific applications such as reversible lanes or solely to provide incident/event management on sections with additional safety considerations.                                                                 | 5.3     |

\(^{25}\) Passenger car equivalent values (pc/h/lane) are used instead of veh/h/lane values to account for presence of heavy vehicles. A heavy vehicle equivalency factor of 1.5 (for level terrain) has been used however it should be noted that factors of 2.5 and 4.5 are applicable for rolling terrain and mountainous terrain respectively.

\(^{26}\) This warrant is only likely to be achieved on a Managed Freeway comprising well-designed infrastructure with CRS in operation.
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| **Priority vehicle facilities**    | ▪ Priority lanes at entry ramps are recommended for freight vehicles where there is sufficient demand on entry ramps providing points of access from major industrial / commercial areas or located on identified freight corridors (e.g. the principal freight network) where there is no adverse impact on the performance of the mainline freeway.  
▪ Generally, a priority lane is recommended for entry ramps where the peak flow is ≥ 600 veh/h with at least 15% heavy vehicles. Each traffic lane should be designed to accommodate a maximum of 600 veh/h.  
▪ For entry ramps with ramp signals, the requirement for a metered or free-flowing lane should be determined on a case-by-case basis and is dependent on the control needed to manage downstream bottlenecks. Due consideration should also be given to the ramp and freeway geometry and required acceleration and merge distances.  
▪ Provisions should be considered for other high-value vehicles, e.g. for public transport on bus priority routes.                                                                                                                                                                                                 | 5.4     |
| **Freeway VMS**                    | ▪ Consider deployment at a spacing of typically 3 km to 5 km on mainline, subject to spacing of significant interchanges and the presence of a LUMS environment.  
▪ Recommend that priority is given to deployment in advance of major decision points including interchanges with high exit flows (peak ramp flow ≥ 1,000 veh/h) where alternative routes are available and they are likely to be used for trip diversion, freeway-to-freeway interchanges, and in advance of LUMS environments. | 6.1     |
| **Arterial road VMS (RTIS / RC3)** | ▪ Install arterial road VMS (RC3) at all entry ramps with ramp signals as per VicRoads’ Managed Freeways Handbook (2010b).  
▪ Consider deployment of RC3 signs at unmetered ramps with a high traffic movement from the arterial road to the freeway (peak ramp flow ≥ 600 veh/h).  
▪ Consider deployment of arterial road VMS in remote locations in advance of major arterial route intersections where there is an alternative ‘parallel’ route available to reach similar significant end-destinations to the freeway. | 6.2     |
| **Vehicle detectors**              | ▪ Deploy at spacing of 500 m on mainline freeway, at interchanges (including ramps) and other locations as required for operation of control interventions.                                                                                                                                                                                                                                                          | 7.1     |
| **CCTV (incident verification)**   | ▪ Full and unobscured coverage of freeway is required with spacing at typically 1 km for straight alignments or more frequently for complex sections with curved alignments. Overlapping coverage should be considered for key bottleneck and incident locations.                                                                                                                                                                                                 | 7.2     |
| **Emergency telephones (incident detection)** | ▪ Deploy as per existing Main Roads ‘Emergency Telephone Guidelines’ provided on website.  
▪ In addition, for sections of carriageway with no emergency lane on a part-time or permanent basis, then emergency telephones must be provided at all emergency stopping bays and not on the mainline carriageway.                                                                                                                                                                                                 | 7.4     |
| **Travel-time calculation**        | ▪ Required to support provision of real-time travel-time information via roadside VMS or pre-trip and in-car services, as well as freeway performance evaluation.                                                                                                                                                                                                                                                             | 7.5     |
| **Other**                          | ▪ Other ITS interventions providing control, traveller information and network intelligence functions should be deployed in accordance with the guidance provided in this document.                                                                                                                                                                                                                                              | 5, 6, 7 |
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