Smart Freeways Provision Guidelines

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For comments or further information, please contact Acting Network Operations Planning Manager, Bita Charehjoo, phone: (08) 9323 4439, email: bita.charehjoo@mainroads.wa.gov.au.

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Smart Freeways Provision Guidelines

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Owner	Mehdi Langroudi, Director Congestion and Movement Strategy
Custodian	Bita Charehjoo, Acting Network Operations Planning Manager
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Prepared by	Maurice Burley, Traffic and Road Safety Consultant
Reviewed by	Adam Reynolds, Transport Planning Leader – Aurecon Kamal Weeratunga, Acting Manager Network Performance
Approved by	Mehdi Langroudi, Director Congestion and Movement Strategy

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September 2012	Main Roads' Managed Freeways Provision Guidelines Original document	All
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Foreword

Smart Freeways policy and guidelines

The Main Roads Western Australia (Main Roads) Smart Freeways policy and various guidelines influence overall planning, project development, delivery and ongoing operation of Smart Freeways in Western Australia.

The Smart Freeways documents were originally developed as part of the Managed Freeways policy framework in 2012. At that time Main Roads used the term 'Managed Freeways', which was changed to 'Smart Freeways' at the time of the first Smart Freeways project on Kwinana Freeway northbound. The 2020 updated documents supersede the previous Managed Freeways documents.

Historically, intelligent transport systems (ITS) on freeways were typically considered case by case. Our current approach is outlined in the Smart Freeways Policy, which states that all freeways are considered for ITS provision at either foundation or higher-order standard according to these guidelines.

The Main Roads' Smart Freeways policy and guidelines comprise the documents listed in the table below. This document is shown highlighted.

Document	Description
Smart Freeways Policy	One page high-level policy statement setting out Smart Freeways objectives and principles.
Smart Freeways Policy Framework Overview	Smart Freeways context, principles, corporate governance, processes and intended outcomes to achieve policy objectives.
Smart Freeways Provision Guidelines	Guidelines and warrants for application of Smart Freeways traffic management treatments and ITS devices.
Smart Freeways Operational Efficiency Audit Guidelines	Guidelines for formal examination of traffic analysis and design of all freeway projects.
Guidelines for Variable Message Signs	Guidelines for the design and use of variable message signs for traveller information for safe and efficient travel for road users.
Supplement to Victoria's Managed Motorway Design Guide, Volume 2: Design Practice, Parts 2 and 3	Main Roads' Supplement relating to: • Network optimisation tools (benefits and operation of coordinated ramp signals). • Planning and design for mainline, entry ramps (including ramp signals), exit ramps and interchanges.
Supplement to Victoria's Managed Freeways Handbook for Lane Use Management and Variable Speed Limits	Main Roads' Supplement relating to: • Lane use management system (LUMS). • Variable speed limits (VSL).

Smart Freeways concept

Smart Freeways make the best use of the existing freeway network, particularly during times of high demand and traffic incidents. We use an ITS and operational strategies that enable dynamic network management and operation in real-time. Smart Freeways traffic management initiatives, complemented by 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.

Over recent years, Victoria's approach to managed motorways in Melbourne has achieved unparalleled, sustainable benefits to freeway operations for safety, productivity, efficiency and reliability. We have applied the same holistic principles and learnings, while also working towards national consistency.

Smart Freeways design and operations should consider both the perspective of the road user and the road operator:

- **Road user** – Smart Freeways provide a better driving experience and meet he road user's expectations for safe and reliable travel on a preferred traffic route.
- **Road operator** – Smart Freeways meet the road operator's need for the most efficient and productive use of existing and proposed freeways through real-time monitoring and effective control of traffic.

Traffic flow theory

Understanding contemporary traffic flow theory is critical for the design of Smart Freeways. Traffic data from our existing freeways shows similar characteristics of flow breakdown and capacity loss to that demonstrated by research elsewhere in Australia and 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 about 2,000 veh/h/lane for a short period time to 1,450 veh/h/lane during the afternoon peak period. This means that a four-lane freeway is only delivering the throughput of a three-lane freeway (approximately 6,000 veh/h), thus effectively losing a lane of freeway capacity.

A consistent approach to Smart Freeways design can be applied across all freeways as the principles of flow breakdown and capacity loss are universal. Flow breakdown is probabilistic, and data from Perth's freeways indicate that there is a 10 per cent 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 Smart Freeway planning.

Recent traffic flow research, supported by field observations from current Smart 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) on the mainline with coordinated ramp signals. These can minimise flow breakdown, and in most cases with a well-designed and operated system, prevent congestion. Coordinated ramp signals (CRS) can also work to restore traffic flow faster by limiting demand in case of flow breakdown, e.g. due to an incident.

Best practice operations use critical occupancy (as a surrogate for density in controlled systems as it is easier to measure), just before the time that capacity flow occurs. This manages the freeway flow, as unlike capacity, critical occupancy is fairly stable even under adverse weather conditions. The occupancy measurement is the most appropriate parameter for optimising throughput, rather than speed or flow rate.

Design warrants for traffic management and ITS devices

Smart Freeways project development and design should begin with traffic analysis to identify current (and future) network performance and factors that could contribute to recurrent flow breakdown and congestion, as well any safety issues. This will inform the design and help a 'toolkit' of ITS technologies to be applied.

Operational strategies form these functions:

- **Control** – of freeway access, lane use and speed to provide safety and capacity improvements, and to support incident, event and congestion management. Treatments include ramp signalling, lane use management systems (LUMS) for dynamic use of the traffic lanes, variable speed limits and priority vehicle facilities.
- **Advice** (traveller information) – to enable road users to make informed route choices and improve safety during incidents. Devices include freeway and arterial road variable message signs that rely on network intelligence.
- **Monitoring** (network intelligence) – by the freeway control system and road operator, to collect and provide traffic and network data to support freeway control and traveller information. Devices and systems include vehicle sensors, CCTV cameras, travel time algorithms and automated incident detection (AID).

The traffic management control systems and devices shall be considered for deployment at two levels dependent on the traffic volumes (existing or design forecasts) of the section of freeway, and the potential of flow breakdown and congestion. The two levels are foundation level of ITS and Smart Freeways with higher-order ITS.

Foundation level of ITS

Our policy is that all freeways will as a minimum have:

- real-time network monitoring and intelligence capabilities, and
- provision for higher-order Smart Freeway treatments, when needed.

This means that all current and future projects on the existing and planned freeway network shall incorporate a foundation level of ITS. This also includes providing roadside traveller information and considering ramp layouts to facilitate future retrofitting of ramp signals.

Smart Freeways with higher-order ITS

A Smart Freeway is one comprising well-designed infrastructure. Where higher-order ITS devices (i.e. above foundation-level ITS) cannot be used, and at least CRS have been applied to achieve our objectives for optimal freeway performance.

Additional devices and control may also be applied depending on local conditions or as required by these guidelines. For further guidance on what constitutes a Smart Freeway, see the Main Roads' Smart Freeways Policy Framework Overview.

A successful Smart Freeways project may require a combination of geometric, civil upgrades and ITS technology improvements. The design life assessment for Smart Freeway projects takes into account different design life assumptions for ITS technology improvements compared with traditional civil works.

Abbreviations

ALR	All lane running
AADT	Annual average daily traffic
AAWDT	Annual average weekday traffic
AID	Automated incident detection
ANPR	Automatic number plate recognition
CCTV	Closed circuit television
CIC	Customer Information Centre
CMS	Changeable message sign
CRS	Coordinated ramp signals
DMS	Dynamic message sign
ESL	Emergency stopping lane
GPS	Global positioning system
ICT	Information and communications technology
IRS	Incident response service
ITS	Intelligent transport systems
LUMS	Lane use management system
LUS	Lane use sign
PMTZ	Partially managed transition zone
PTA	Public Transport Authority
PTZ	Pan, tilt and zoom
RC1	ramp control sign 1
RC2	ramp control sign 2
RC3	ramp control sign 3
RNOC	Road Network Operations Centre
RTMT	Real-time monitoring team
RTTO	Real-time traffic operations
SCATS	Sydney Coordinated Adaptive Traffic System
SF	Smart Freeways
STREAMS	ITS control system currently in use by Main Roads
TCSN	Traffic control system network
TIRTL	The Infra-Red Traffic Logger
TOC	Traffic Operations Centre
UPS	Uninterrupted power supply
VDS	Vehicle detection station
VMS	Variable message sign or signs. This generic term may include dynamic message signs (DMS) and changeable message signs (CMS).
VSL	Variable speed limit

WA	Western Australia
WAPOL	Western Australia Police
WIM	Weigh-in-motion

Contents

1 Introduction

1.1 Smart Freeways policy and guidelines

Main Roads has a policy and series of guidelines for the design, implementation and operation of Smart Freeways in Western Australia. A summary of the series of Smart Freeways documents is provided in Table 1.1.

Table 1.1 Smart Freeways policy framework documentation

Document	Description
Smart Freeways Policy	One page high-level policy statement setting out Smart Freeways objectives and principles.
Smart Freeways Policy Framework Overview	Smart Freeways context, principles, corporate governance, processes and intended outcomes to achieve policy objectives.
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1.2 Purpose of document

This document is for deployment of Smart Freeways on the existing and future freeway network in Western Australia. The document covers the following key topics:

- Background on the Smart Freeways concept (Section 2).
- Introduction to contemporary traffic flow theory and implications for Smart Freeways design (Section 3).
- Guidance on Smart Freeways design, covering freeway mainline and ramp traffic analysis, design-life assumptions, overview of the ITS technologies in the Smart Freeways 'toolkit', and priorities for application (Section 4).
- Details on the two levels of ITS provision and associated warrants, including foundation level ITS and higher order ITS (Section 5).

- Detailed provision guidelines for each traffic control measure or ITS device, including description and purpose, warrants and application guidelines, and technology and installation configurations (Sections 6, 7 and 8).
- Description of foundation infrastructure required to support Smart Freeways (Section 9).

Any deviation from these guidelines shall be considered under the extended design domain and agreed with Main Roads, as outlined in the Main Roads' Smart Freeways Policy Framework Overview.

1.3 Acknowledgements and process

These guidelines were originally developed as Managed Freeways Provision Guidelines (2012) by ARRB Group Ltd.

In this revision, the original document was comprehensively updated within the oversight of a steering committee comprising key managers in Network Operations, and Planning and Technical Services and in consultation with the main internal and external stakeholders.

Main Roads also considered practices in Victoria when developing these guidelines.

2 Smart Freeways concept

2.1 Overview

Smart Freeways make the best use of the freeway network by improving safety, productivity (throughput and travel speed), and reliability, particularly during times of high demand and traffic incidents.

In Smart Freeways, ITS technologies, complemented by sound mainline and ramp geometric design integrated with real time traffic operations are used to achieve, and maintain, dynamic, optimal traffic conditions, with minimal delays and congestion.

While recognising that a Smart Freeway may include a range of ITS devices and systems, a coordinated ramp signal system is the primary form of traffic management for avoiding flow breakdown and congestion as well as recovering from congested situations.

2.2 Road user and road operator perspectives

An actively managed freeway aims to address both road user and road operator traffic management expectations and perspectives as described in Table 2.1

The Main Roads' Smart Freeways Policy Framework Overview (2020) highlights that not every section of a Smart Freeway needs to include all the treatments available within the 'toolkit'. Traffic control and ITS devices shall be applied according to warrants and need on the network or provide an identified user service. There are some traffic management controls that are critical to effective operation of a Smart Freeway, e.g. coordinated ramp signals, whereas others may be considered as less critical, to provide an enhanced level of service or address problems at specific locations.

The following series of graphics in Figure 2-1 to Figure 2-5 show how the traffic management controls from the Smart Freeways toolkit and the combined use of network intelligence, traffic control and traveller information contributes to a Smart Freeway environment.

Figure 2-1 Coordinated ramp signals on the entry ramps of the freeway

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 sensors enable adaptive operation of the ramp signals and closed-circuit television (CCTV) cameras allow monitoring of traffic conditions.

Table 2.1 Road user and road operator perspectives of Smart Freeways

Road user perspective	Road operator perspective
The Smart Freeway provides an enhanced driving experience and meets the road user's expectations for safe and reliable travel on a preferred traffic route	The Smart Freeway meets the road operator's need for the most efficient and productive use of existing freeways through real time monitoring and control of traffic
Safe travel environment that reflects real-time road conditions and appropriate speed limits	Real-time and reliable data on traffic and network conditions to assist traffic control and provision of traveller information Minimise crashes through sound design and operations
Travel at satisfactory, but not necessarily free-flow speeds, throughout the day	Minimise flow breakdown and optimisation of freeway capacity through optimal management of the traffic flow Optimise network productivity to assist efficient and economic travel to road users
Reliable travel time, with only a small buffer required in trip planning	Rapid restoration of traffic flow in the event of flow breakdown due to an incident
Timely and advanced warning of freeway conditions and disruptions, in order to make appropriate decisions on alternative routes and / or modes	Real-time control on freeway access, lane use and speed limits, in response to changing travel condition
Once on the freeway, near real-time information of downstream freeway conditions, disruptions and hazards, and advice on appropriate actions to be taken	Influence real time route choice, in response to changing travel conditions or to assist priority for specific users
Consistent and clear instructions on mandatory lane closures and variable speed limits	Effective management of congestion and incidents, including priority access to emergency services and quick clearance, through reliable and prompt detection and verification of incidents and disruptions as well as timely provision of traveller information
Enhanced road user experience	User-friendly control system and user interface for easy and effective operation of all ITS devices on the network

Source: Adapted from VicRoads (2010a)

Figure 2-2 Integrated speed and lane use management system on 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. with no emergency lane (emergency stopping bays provided).

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

Figure 2-3 Real-time travel-time information displayed on arterial road VMS on the approach to the freeway

Source: VicRoads (2010a)

Figure 2-42 Tactical VMS on the Kwinana Smart Freeway

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

In addition to the on-road environment, another key element of Smart Freeways is a comprehensive Road Network Operations Centre (RNOC), where traffic operators undertake ongoing network surveillance and incident management. Real-time operations are supported by traffic operations specialists and systems engineers that undertake system performance tuning (optimisation) and fault management.

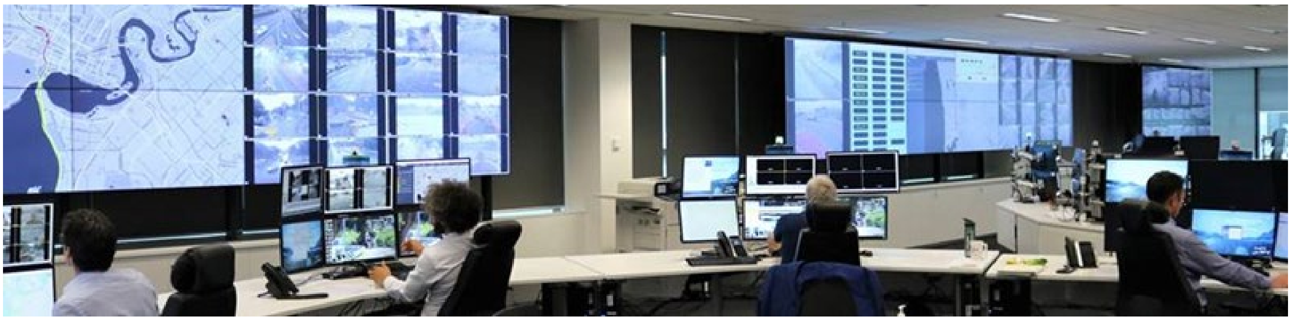

Figure 2-53 Traffic operators dynamically monitoring the network in real-time

3 Traffic flow theory for Smart Freeways

This section is an overview of the key principles of traffic flow theory informing traffic flow analysis and Smart Freeways design and operations. The summary is largely based on the summary of traffic theory in the Victorian guides, which is described in further detail in the Managed Motorways Design Guide: Volume 1: Managed Motorways – Role, Traffic Theory and Science (2019)[1]. See this guide 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 the available 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 length of freeway.

Figure 3-1 illustrates the impact of flow breakdown in an unmanaged freeway. This example of the Mitchell Freeway southbound in the vicinity of the Whitfords Avenue on-ramp demonstrates a significant drop in speed and a decrease in flow from approximately 1,880 veh/h/lane to 1,400 veh/h/lane during the morning peak period, i.e. a 23 per cent drop per lane, which means freeway capacity has effectively been lost.

This low performance lasted for the duration of the peak period, when high demand means that the freeway needs to perform at maximum capacity. Maximum flow is only achieved for a short time when traffic density is at an optimum value, and then flow breakdown occurs when density rises above this optimum value. Furthermore, the effects of congestion are felt with slow moving queues with shockwave propagation for a significant distance upstream along the freeway.

Further illustration of the performance of unmanaged freeways in Perth during congested periods on a typical weekday is provided in Figure 3-2.

[1] Main Roads has a Supplement (2020) to VicRoads Managed Motorways Design Guide: Volume 2 Design Practice, Parts 2 and 3 (2019), which shall be referred to in conjunction with the VicRoads publication.

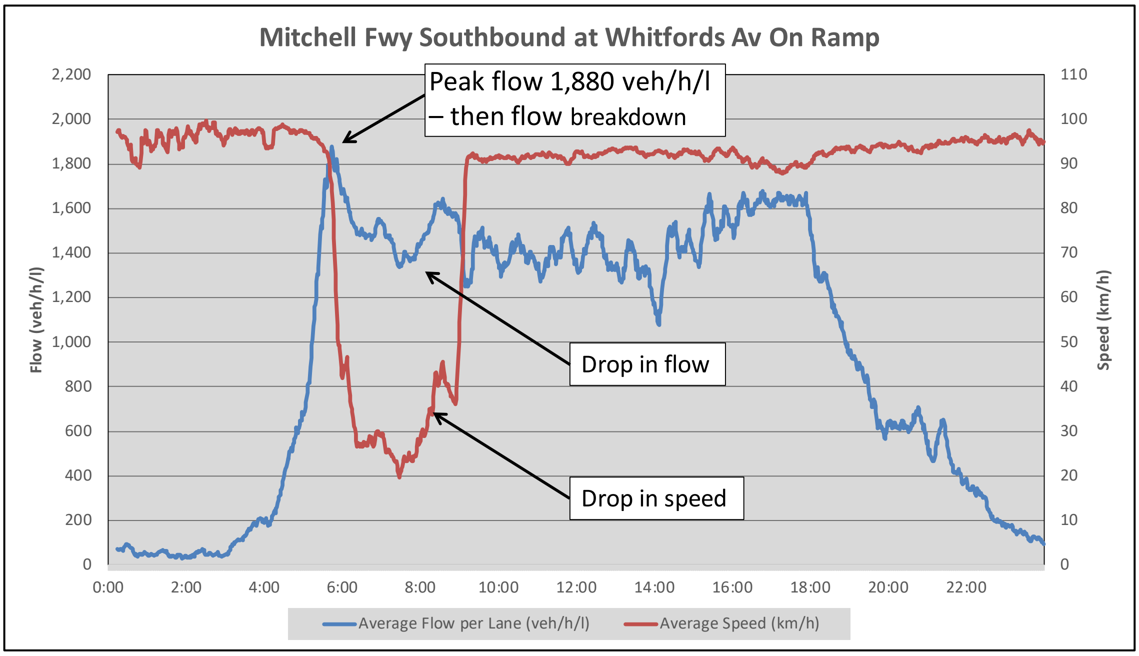

Figure 3-1: Implications of flow breakdown on Mitchell Freeway southbound near the Whitfords Avenue on-ramp

Source: Main Roads (STREAMS) One-minute data, Wednesday 3 April 2019 (Site: 0670MIS-MUL)

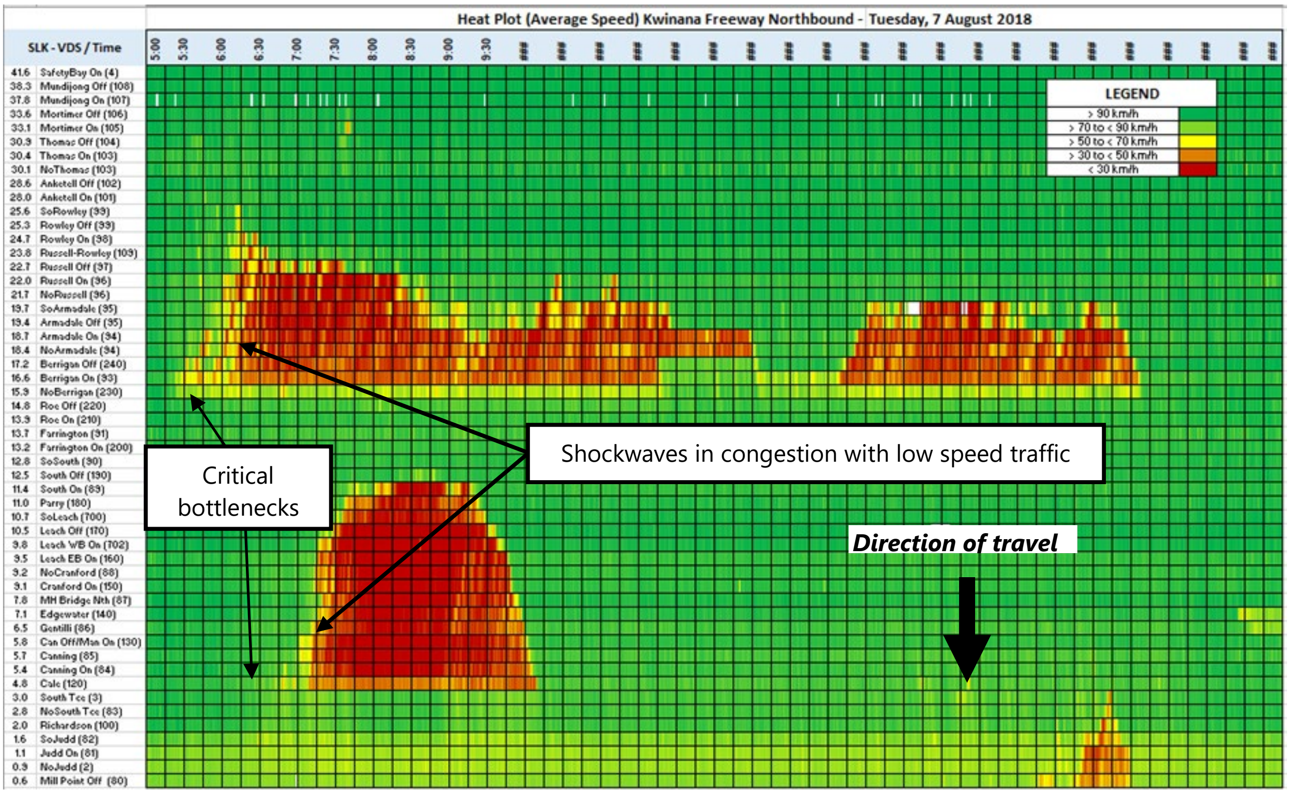

Figure 3-2 Heat plot illustrating critical bottlenecks and subsequent congestion on Kwinana Freeway (northbound) AM peak period

Source: Main Roads Western Australia One-minute (average speed) data for Monday 7 August 2018

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.

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 per cent probability of flow breakdown. Similar values are also evidenced in traffic data from Perth's freeways (see Figure 3-3).

There is also a growing body of research that challenges the traditional assumption that merge and diverge segments have the same capacity as a basic freeway segment. Research by Shawky and Nakamura (2007, cited in ARRB 2012b) demonstrates that an increasing ratio of entry ramp flow to downstream flow rates (merge area outflow) 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 3-4 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.

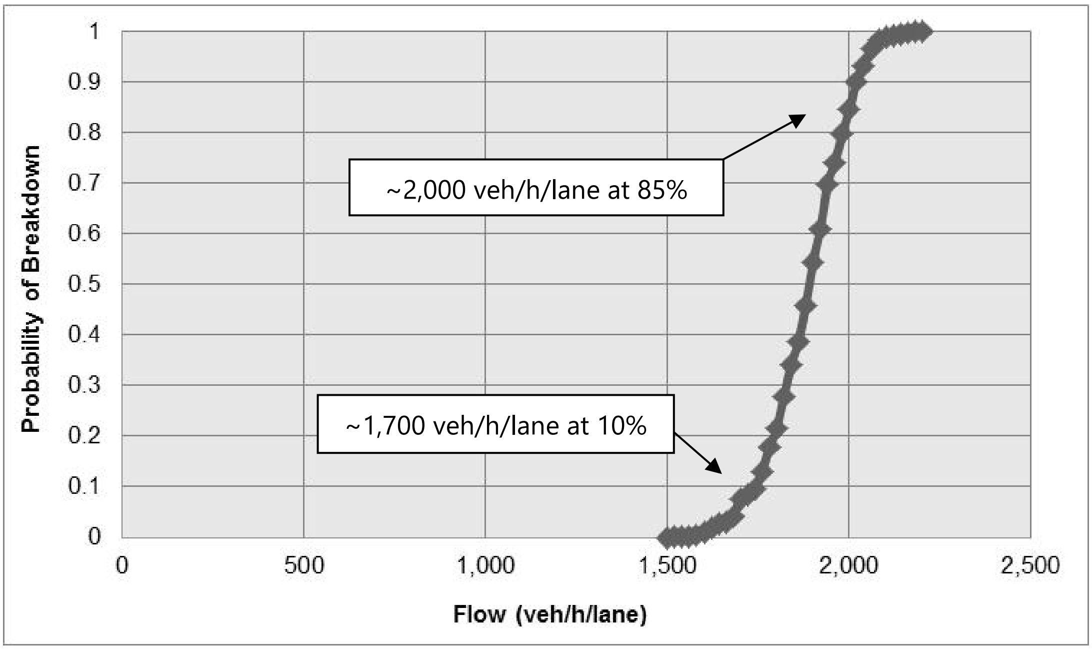

Figure 3-3: Probability of flow breakdown on the Mitchell Freeway (southbound at Whitfords Avenue entry ramp)

Source: Main Roads Western Australia Five-minute data[2].

[2] The graph was produced from freeway mainline data for over 400 days (spanning two years) where flow breakdown occurred at a location of a critical bottleneck on a two-lane freeway just prior to an on-ramp merge. It uses flow values obtained just prior to flow breakdown, where the speed typically drops from around 60-70 km/h to 30-40 km/h.

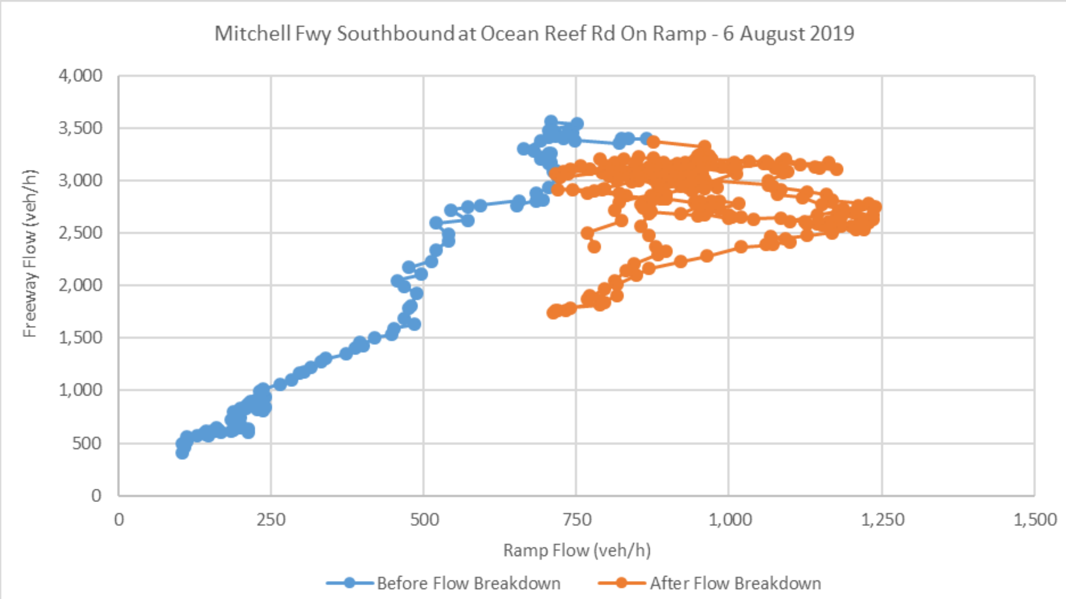

Figure 3-4: Effect of flow breakdown on mainline and ramp volumes - AM peak Mitchell Freeway (southbound at Whitfords Avenue)

Source: Main Roads Western Australia One-minute data (15-minute rolling average) for Monday 6 August 2019 on a representative day where flow breakdown occurred at ~1,700 veh/h/lane.

Appreciation of contemporary traffic flow theory therefore has the following important implications for Smart Freeways design and operations:

- 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 such as shockwave patterns.
- Since freeway capacity at merge and other bottleneck areas is affected by the supply of traffic at entry ramps, understanding mainline flow and capacity analysis is important. Improved capacity at merge or other bottleneck areas that is sustained despite increasing demand, can be achieved by managing the critical occupancy (density) on the mainline with coordinated ramp signals (CRS). In a well-designed and operated freeway, the CRS system controls vehicle access so that the supply of traffic to the freeway is managed within the capacity as shown in Figure 3-5.

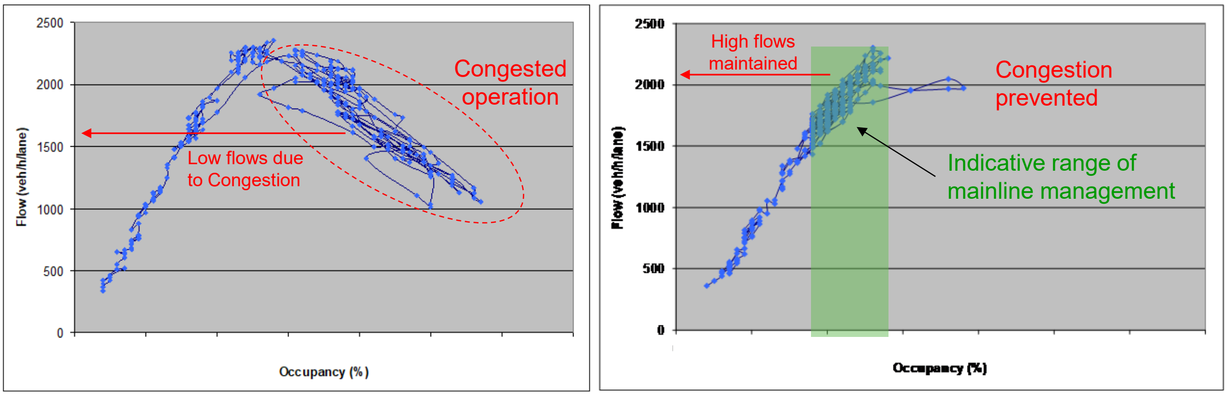

Figure 3-5 Mainline unmanaged flow with flow breakdown (left) and managed flow with CRS (right)

Source: VicRoads

Note: The critical occupancy 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. Occupancy is a surrogate for density in control systems as it is easier to measure.

- Design shall 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 shall also facilitate recovery if flow breakdown does occur, e.g. 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 that can contribute to the diversion of traffic away from the congested area.
- 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 mainline management shall consider the flow level at which flow breakdown is likely to start occurring (i.e. typically 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 (maximum sustainable flow rates), which represent the optimal capacity design flow prior to breakdown, shall therefore be used for mainline and 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 can be determined (see Victoria's Managed Motorway Design Guide Volume 1, Part 3). This varies according to the number of freeway lanes, the percentage of heavy vehicles, the grade and other factors.

This section highlights that an understanding of contemporary traffic flow theory is critical for the design of freeways.

Traffic data from Perth's existing freeways exhibit similar characteristics of flow breakdown and capacity loss to that demonstrated by national and international research. A consistent approach to Smart Freeways design can therefore be applied across all freeways, as the principles of flow breakdown and capacity loss are universal. Investigations have also shown that the safety and productivity benefits of Smart Freeways design and operation are significant.

4 Designing Smart Freeways

The following sections provide general guidance on the recommended approach to Smart Freeways design. This covers freeway analysis, design life assumptions, peak spreading, treatments in the Smart Freeways toolkit, and the priorities for their application to existing and planned freeways in Western Australia.

4.1 Freeway performance and traffic analyses

4.1.1 Analysis of existing freeways

Traffic analysis of an existing freeway to understand operations or as part of Smart Freeway project development may need to consider the following:

- Localised congestion due to bottlenecks caused by merging or geometric constraints, e.g. lane drops. An analysis of the freeway shall be undertaken to identify the traffic demands and the reasons for flow breakdown. Where localised congestion is a problem, this may be due to localised merging or it may be due to excessive demand coming from upstream.
- Extensive lengths of congestion due to flow breakdown at one or multiple locations where significant lengths of freeway are impacted. These operational problems generally require extensive upgrading to the infrastructure as well as operation to manage flows. On some heavily trafficked freeways, it may not always be possible to build additional capacity. In these situations, there needs to be specific attention to managing demands (in order to minimise flow breakdown), as well as design consideration given to managing the demand into the future.

On heavily trafficked freeways, operational problems are generally route-based and need route-based solutions. Freeway traffic analysis of an existing route should therefore be used to identify existing issues on the network, as well as the causes of the congestion, e.g. contribution of traffic demand from upstream and future operating conditions.

Freeway traffic analysis should use validated data (single source of truth for the project) and include detailed route, bottleneck and merge analyses. It should also consider the following investigations in the context of design, for justification of improvements, and for evaluating benefits of proposals, including:

- mainline, entry and exit flows to understand traffic demands
- peak-period profiles (relative to time) of traffic flow, speed and occupancy
- 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 specific locations, e.g. to identify if the data represents congestion from flow breakdown as a result of:
  - a critical bottleneck at that location
  - shockwaves from a critical bottleneck downstream, and
  - 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).

Heat plots derived from vehicle sensors data (see Figure 3-2 for an example) are recommended to support traffic / bottleneck analysis. These help to identify the location, duration and intensity of congestion.

This information, together with project forecast design volumes, will help to identify the most appropriate upgrade measures to address the causes of the flow breakdown and congestion across a section of freeway. For example, it will indicate the required extent of a coordinated (route-based) ramp signal treatment and/or the geometric improvements needed to provide additional 'physical' capacity.

4.1.2 Forecast design traffic and project design life

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

Determining the design life for Smart Freeways ITS treatments shall consider various factors, including (but not limited to):

- level of civil works within the project scope
- current expected life of the existing road, and
- availability of funding.

The following principles may be considered as general guidance, however the detailed assessment shall be documented in the design report for Main Roads consideration during the project planning and development stage:

- If the Smart Freeways design incorporates substantial civil works as well as CRS, then a design life of between 10 years and up to 30 years should be considered for design, e.g. if it caters for traffic volumes up to 20 years after opening, the project benefits in the economic evaluation should be calculated over that period.
- If the Smart Freeway design incorporates primarily ITS interventions with minimal civil works, then it may be appropriate to consider a shorter design life of 10 years, subject to the likely timeframe before any other upgrading.
- The design volumes for specific ITS warrants, e.g. ramp signals, should be considered in the context of the criteria in Sections 5 and 6.

Considering the design life will help determine whether it is better to implement ITS treatments at the time of works and hence avoid the extra costs of retrofitting at a later date. 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. In other cases, the ITS treatments will provide significant benefits and also delay the timeframe for further upgrading as demand continues to increase.

The design life shall be considered in the project's economic evaluation.

4.1.3 Capacity analysis

For some Smart Freeway requirements, the warrants or analyses required are provided in terms of vehicles per hour (veh/h) or passenger cars per hour (pc/h) to account for presence of heavy vehicles in the traffic mix. Capacity values (maximum sustainable flow rates in Victoria's MMDG Volume 2, Part 3) are based on consideration of the number of lanes, grade and proportion of trucks, due to the flow effects of these factors on capacity.

There is significant variation in the proportion of heavy vehicles on Perth's freeways, typically ranging from five to 20 per cent. Where required, the conversions to account for heavy vehicles can generally use a heavy vehicle equivalency factor of 1.5 for level terrain, and with factors of 2.5 and 4.5 for rolling terrain and mountainous terrain respectively.

4.1.4 Impact of peak spreading on peak-hour volumes

Traditionally, traffic engineers have assumed peak hour volumes as 10 per cent of the annual average weekday traffic (AAWDT) volumes or the 24-hour strategic modelling outputs (also known as the K factor). However, with increasing congestion, accompanying peak spreading and greater freeway use during the inter-peak period, use of the peak-hour / daily volume ratio calculation is decreasing.

Data analysis suggests that this ratio is currently around eight per cent for Perth's freeways and key arterials due to congestion, peak spreading and other factors. However, there is concern about using an eight per cent value to convert 24-hour forecast volumes, as it assumes congestion will be present, i.e. the true traffic demand may not be accommodated so that the freeway can operate without congestion.

Therefore, where ratios are being determined from existing flow data, it is based on the real short-term demand before flow breakdown and congestion, (i.e. the 15-minute flow rate and not the one-hour flow). This value is typically in the order of 8.5 to nine per cent, where there are high traffic volumes during the inter-peak period.

The Smart Freeways concept derives from performance-based design, with a focus on minimising flow breakdown and congestion. Therefore, when determining realistic assumptions for peak/24 hour volume calculations, see the Main Roads' Supplement and Victoria's MMDG Volume 2, Part 3 where this is discussed in more detail.

4.1.5 Safety analysis

The Smart Freeways geometric design and technology treatments can provide significant safety benefits, e.g. at locations where high accident rates are experienced.

Safety analysis should generally 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, e.g. CRS to minimise the occurrence of congestion are supported due to safety considerations. It may also help determine whether a lane-use management system will be required to support managing incidents. A further benefit of LUMS is minimising the occurrence of secondary incidents by diverting traffic safely around the incident and reducing speeds to provide queue protection and to reduce the risk to incident responders.

4.2 Toolkit of technology treatments for Smart Freeways

The 'toolkit' of technology treatments 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 time reliability, efficiency, safety and sustainability benefits to the community. In line with Main Roads' objectives, Smart Freeways also need to provide an enhanced road user experience and develop 'smart' roads in preparation for future cooperative ITS (ARRB 2012a and Main Roads 2012a).

There are several treatments that can be used to achieve Main Roads' objectives for freeway network. These can be considered in terms of three key ITS service or functional categories:

- control
- advice (traveller information), and
- monitoring (network intelligence).

The deployment of ITS treatments on a section of freeway shall also be supported by foundation infrastructure.

The following sub-sections provide a brief description of each category and associated interventions, with further details provided in Sections 6, 7, 8 and 9.

4.2.1 Control treatments

ITS providing real-time traffic control is the key treatment that delivers 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 lane use (and speed) of vehicles on the mainline.

Capacity improvements are achieved by:

- ensuring the full operational capacity of the freeway is used at all times, including periods of high demand, through CRS with appropriate entry ramp designs
- providing additional physical capacity as required, i.e. pavement widening for additional lanes, or other improvements, and
- in some areas, providing additional 'physical' capacity as required, i.e. using the full pavement with all lanes running by converting the emergency lane, generally on a full-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 help 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 such as emergency services.

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

Table 4.1 Key ITS services providing control functions

ITS traffic management and control function	Related ITS technology	Section
Ramp signalling Implemented as a corridor-wide treatment, e.g. coordinated ramp signalling (CRS) including freeway-to-freeway ramp signalling, or limited use as 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.	Supported by a state-of-the-art ramp signalling system, network intelligence and traveller information	6.2
Lane use management systems (LUMS)[3] 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) and reversible lanes) • incident and event management.	Supported by network intelligence and traveller information	6.5
Variable speed limits (VSL)[4] Provides speed control to achieve: • incident and event management (in association with lane use management) • queue protection • capacity improvement i.e. support of CRS in optimising capacity.	Supported by network intelligence and traveller information	6.4
Priority vehicle facilities at entry ramps	Freight or bus route priority	6.2.3
Arterial road traffic control Can be used to support Smart Freeway operation, e.g. to ensure exit ramp queues are cleared	Arterial road traffic signals and sensors (SCATS)	6.3

Note: Smart Freeways design may also need to consider potential future requirements for compliance monitoring (Section 6.6).

4.2.2 Traveller information

Providing real-time traveller information via roadside equipment (or in-vehicle devices) 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 generally considers 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, and
- en-route on the freeway network.

[3] LUMS incorporates variable speed limits through combined use of overhead LUMS signs, unless there are specific geometric constraints, i.e. in tunnel environments.

[4] VSL is generally integrated with LUMS through combined use of overhead LUMS signs. See Section 6.4.

En-route information can be provided through roadway 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 roadway signs can also be used to provide warning in advance of hazards on particular sections of the network, and information on planned events.

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

Table 4.2 Key ITS services providing traveller information functions

Key ITS service	ITS and technology elements	Section
Roadway traveller information, i.e. travel-times, traffic conditions, incident and hazard warning and other message displays	• Freeway variable message signs (VMS) • Freeway-to-freeway VMS • Arterial road VMS (including RC3 signs as part of ramp signalling design) • Public transport VMS	7.1 7.4 7.5 7.6
Roadside hazard warning	• Advance warning flashing signals including over-height vehicle detection and warning	7.7
Non-roadside traveller information	• Pre-trip and in-car traveller information systems	7.8

Note: Smart Freeways design should also consider other information such as fixed signing and lane markings (Section 7.9).

4.2.3 Network intelligence functions

Network intelligence functions are fundamental to Smart Freeways operations. Real-time network intelligence involves collecting and analysing traffic and other data to support control and traveller information devices, as well as incident detection and verification. This usually includes 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 required to deliver these functions are listed in Table 4.3.

Table 4.3 Key ITS services delivering network intelligence functions

Key ITS service	ITS and technology elements	Section
Real-time traffic data collection	• Vehicle sensors (on mainline and ramps) • Arterial road traffic data (SCATS data) • Bluetooth scanners	8.1 8.3
Travel time calculation	• Travel-time calculation*	8.5
Incident detection	• Closed circuit television (CCTV) cameras • Automated incident detection (AID) system* • Roadside help phones • Communications and data sharing with internal and external stakeholders	8.2 8.6 8.4 8.7
Incident verification	• CCTV cameras	8.2
Real-time environmental data collection	• Environmental monitoring systems	8.8

**Note: These elements may, or 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 sensors.*

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 Smart Freeways.

The ITS and technology elements that provide Smart Freeways foundation infrastructure are listed in Table 4.4.

Table 4.4 ITS and technology elements for Smart Freeways foundation infrastructure

ITS and technology elements	Section
Communications network	9.1
Power network	9.2
Road Network Operations Centre (RNOC)	9.3
Smart Freeways control system	9.4
Freeway performance evaluation	9.5
System performance management	9.6
Other considerations	9.7

Foundation infrastructure design shall also identify any potential civil modifications, e.g. ramp layout / design, to assist with retrofitting of Smart Freeways treatments or ITS devices.

5 Levels of ITS for Smart Freeways

The freeways in Western Australia that require ITS technologies are defined within the Main Roads' Smart Freeways Policy Framework Overview (2020). The general warrants and prioritisation for determining which ITS treatments will be incorporated in Smart Freeways design are provided below.

Providing ITS traffic technologies is based on evidence of the effectiveness of different Smart Freeways treatments, particularly CRS, which have been implemented by other Australian road authorities (particularly in Victoria) as well as some international road agencies.

To align with Smart Freeways Policy (2020), the selection of technology and operational strategies shall take into account objectives and desired outcomes, as well as the nature of the problems as identified by network analysis, based on validated data.

ITS treatments shall be considered for deployment at two levels, generally based on the average per hour, per lane design traffic volumes in the peak direction (existing or forecast according to project scope). The two levels of ITS provision are:

- foundation-level ITS (see Section 5.1) which includes design provision for future upgrading to higher order Smart Freeways ITS, and
- Smart Freeways higher-order ITS technologies (see Section 5.2).

5.1 Foundation-level ITS and warrants

Main Roads' policy is that all existing (including upgrades), and new freeways will, as a minimum, have real-time network intelligence and monitoring capabilities, and provision for higher-order Smart Freeways treatments when needed. This will also include provision of roadside traveller information according to the requirements below.

Warrants:

Foundation-level ITS applies to all freeways and higher-order, controlled-access highways as defined in the Smart Freeways Policy Framework Overview (2020).

Table 5.1 summarises the requirements for deployment of ITS technologies, including relevant foundation infrastructure. These are the minimum requirements for all existing and future freeways, including existing roads to be upgraded to freeway standard, with exceptions considered under the extended design domain process.

The provision for future higher-order ITS technologies means that ITS route strategies and concept design for ultimate needs shall be carried out. The foundation level treatments can then be a staging of longer-term needs, e.g. even though a reduced number of vehicle sensors or VMS may be provided in the initial construction, the locations are consistent with ultimate needs.

Similarly, ramps shall be designed to suit future retrofitting of higher order Smart Freeways ITS, particularly in relation to control measures such as CRS for future freeway mainline management, e.g. ramp lengths and widths, location of vehicle sensors, etc.

Table 5.1 Foundation-level ITS requirements

ITS technology	Warrants and approval guidelines	Section
Freeway VMS	• Should be deployed at spacing of typically 5 to 10 km on mainline (approximately 50% of higher order ITS), subject to spacing of significant interchanges and presence of key bottleneck and high risk incident locations. • Priority should be given to deploying in advance of major decision points including exit ramps with high flows (peak ramp flow ≥ 1,000 veh/h) where alternative routes are available and they are likely to be used for trip diversion.	7.1
Freeway-to-freeway VMS	• Should be considered in advance of freeway-to-freeway interchanges, particularly where traffic data, i.e. VDS, are available on the intersecting freeway and/or alternative routes are available for trip diversion.	7.4
Vehicle detection systems	• Vehicle sensors shall be deployed at spacing from 500 m to 2 km on mainline freeway between interchanges (approximately 50% of higher order ITS), within all interchanges (including ramps). • As required for traffic counting to inform historical performance analysis and planning activities.	8.1
CCTV cameras (for incident verification)	• Shall be provided for 100% coverage. A higher level of coverage, e.g. overlapping coverage, may be considered at specific locations where network surveillance is beneficial, such as priority at interchanges, bottlenecks where congestion may occur and complex sections with high lane changing or weaving.	8.2
Roadside help phones	• Shall be deployed as per Main Roads' Guideline: Emergency Stopping Bays and Roadside Help Phones.	8.4
Travel-time algorithms	• Should be provided to support use of real-time travel-time information via roadside VMS or pre-trip and in-car services, as well as freeway performance evaluation.	8.5
Power and communications (foundation infrastructure)	• Separate longitudinal conduits for electrical and communications cables shall be provided. • Electrical and communications cabling shall service the complete length of the corridor with adequate capacity for future higher-order ITS requirements, although in some situations other options may be appropriate, e.g. local power supplies. • Separate pits for communications and power shall be provided at all changes in direction and maximum spacing of 250 metres on straight mainline sections (considering typical spacing of ITS field equipment at 500 metres), as well as appropriate on ramps.	9.1 & 9.2
Other systems	• Other ITS devices or systems should be used according to project-specific needs. • All entry ramps shall be designed for future implementation of CRS.	7 & 8

5.2 Higher-order ITS and warrants

A Smart Freeway with higher-order ITS shall comprise well designed infrastructure to minimise flow breakdown and at least foundation-level ITS and coordinated ramp signals (CRS) to achieve Main Roads' objectives for optimal freeway performance. Additional systems and devices shall be considered, as outlined below.

Warrants

Higher-order ITS applies to all freeways where the peak-direction mainline design volume forecast at the estimated date of project completion is ≥ 90 per cent of the applicable maximum sustainable flow rate (MSFR) for unmanaged freeways design (see Main Roads' Supplement to Victoria's Managed Motorway Design Guide), and the rationale below.

The MSFR values vary according to the number of lanes, grade and proportion of trucks, due to the flow effects of these factors on capacity. For relatively flat grades (≤ two per cent), the 90 per cent MSFR values generally equate to:

- 3,200 pc/h for two-lane carriageways
- 4,640 pc/h for three-lane carriageways, and
- 5,960 pc/h for four-lane carriageways.

The volume warrant applies to any segment along the freeway project (within or between interchanges) as well as downstream sections of freeway as outlined in Section 6.2. The warrant in passenger cars is to account for heavy vehicles in the traffic mix, i.e. where forecast volumes are in veh/h these shall be assessed relative to equivalent MSFR values (see Section 4.1).

Various warrants and guidance apply to the different ITS technologies. Table 5.2 summarises guidance and requirements for deployment of higher-order ITS. Section 6 includes more detailed guidance.

Although the above warrants for higher-order ITS technologies are based on forecast traffic at the date of opening, longer periods of time are applicable for determining forecast traffic volumes for design as indicated in Section 4.1.2.

Higher-order ITS requirements are also applicable on sections of existing freeway where flow breakdown and congestion occur on a recurrent basis, such as due to traffic demand, at volumes lower than the warrant thresholds (also see Section 6.2), as determined by freeway traffic analysis. An indicator of recurrent congestion is when average peak period travel speeds are approximately 60 per cent or less of the posted speed limit. A combination of CRS and ramp geometric improvements would generally be required as a minimum.

Foundation-level requirements shall be provided as indicated in Section 5.1 on freeways requiring higher-order ITS. Consideration for higher-order ITS is relevant for all existing and future freeways, including existing higher-order arterials to be upgraded to freeway standard, with exceptions to be considered under the extended design domain process.

Designs shall be developed in accordance with the Main Roads' Smart Freeways Supplement to Victoria's MMDG Volume 2: Parts 2 and 3 and other Main Roads' guidelines.

As general guidance for Smart Freeways design for retrofitting existing freeways, all critical mainline bottlenecks causing recurrent congestion should be considered for suitable geometric upgrade options as well as retrofitting the freeway with CRS at sufficient entry ramps to enable adequate mainline management.

Minor geometric mainline improvements or ramp modifications, i.e. civil upgrades, shall be investigated to improve the operational efficiency of the freeway. Examples include:

- additional lane or changed exit arrangements 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)
- increasing exit ramp storage to prevent vehicles queuing back onto the mainline
- increasing entry ramp length or width to achieve the desirable standard for ramp discharge capacity (number of lanes at the stop line) and storage upstream of the stop line, and
- auxiliary lanes to cater for high on / off flows between two interchanges, if traffic analysis indicates it will be utilised to address a weaving problem.

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.

All projects being considered are subject to traffic analysis to determine problem areas needing to be addressed, determination of appropriate design volumes and rigorous volume / design capacity analysis. A successful Smart Freeways scheme is likely to require a combination of geometric improvements and ITS technologies.

5.2.1 Deployment of traffic control strategies

Coordinated ramp signalling (CRS)

CRS shall be provided on all Smart Freeway projects requiring higher-order ITS (existing freeway upgrades and new freeways). CRS are the most effective ITS tool for improving safety and productivity. CRS in a well-designed and operated system that aims to maintain mainline traffic density (occupancy) at or near critical density (occupancy) by controlling the entry ramp inflows, thereby preventing or minimising 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 generally a route-based treatment where the number and extent of CRS can be determined as part of the project development process. On a heavily trafficked freeway network, isolated ramp signals are generally unable to manage demand but could also be investigated to address localised problems.

Deployment of CRS applies to all freeways where the peak-direction mainline design volume (see Section 4.1.2), forecast 10 years after the estimated date of project completion is ≥ 90 per cent of the applicable maximum sustainable flow rate (MSFR) for unmanaged freeways design (see further detail and rationale in Section 6.2).

The volume warrants above are based on the probabilistic rather than deterministic nature of flow breakdown as shown by:

- VicRoads investigations of flow breakdown risk (FBR) – see example for unmanaged freeways in Victoria’s MMDG Volume 1: Part 3 (see Figure 5-1)
- Brilon et al (2005): research on probability of flow breakdown, and

- Elefteriadou et al (1995): reaching capacity flows is not a prerequisite for flow breakdown - clusters of ramp vehicles affect the motorway merge operation.

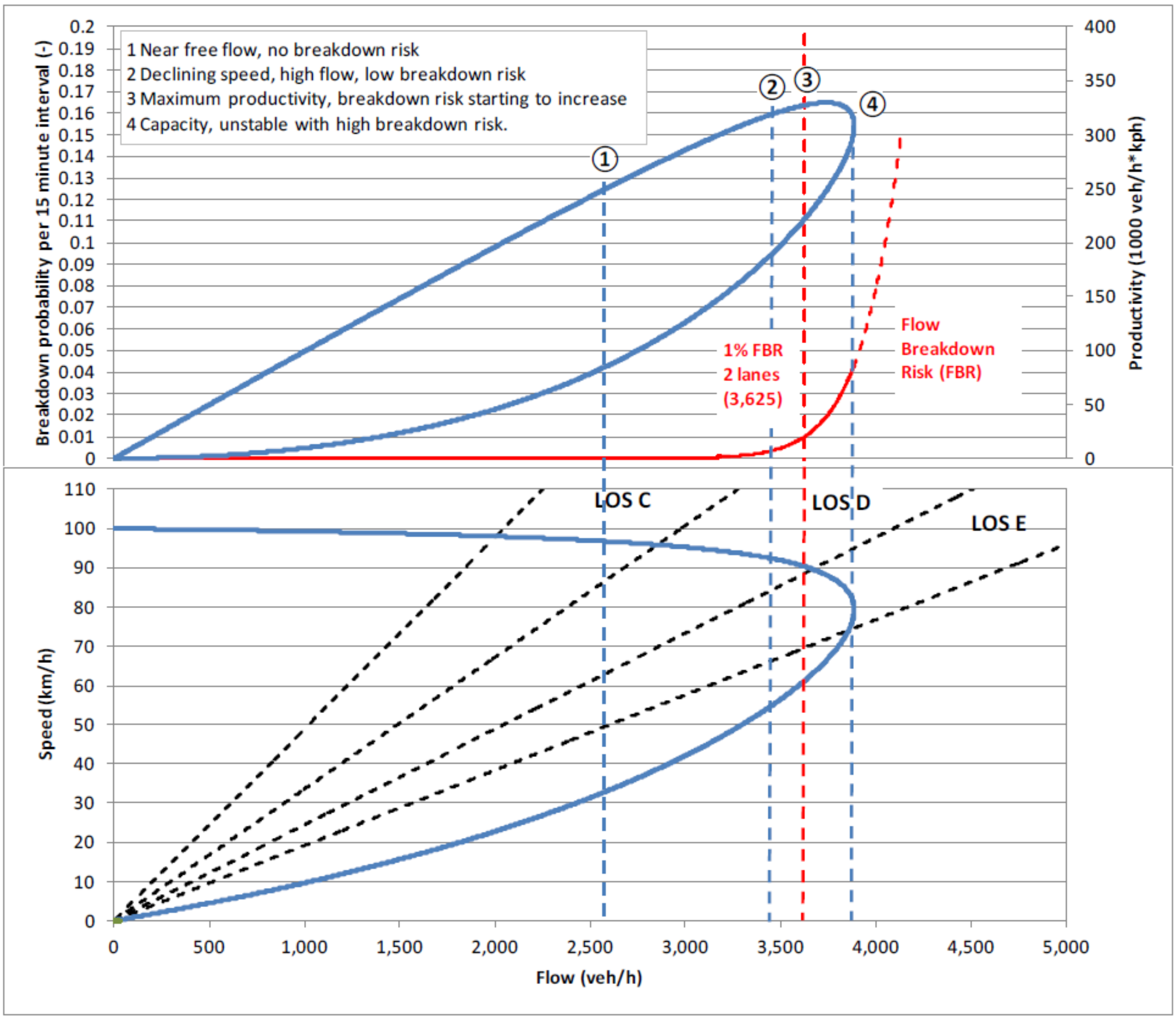

Figure 5-1 Example of flow breakdown probability and productivity relative to flow rate and level of service (two-lane carriageway)

Source: VicRoads (MMDG Volume 1, Part 3)

Lane use management systems (LUMS) integrated with variable speed limits (VSL)

LUMS integrated with VSL for all lane running (ALR) projects shall be deployed to facilitate incident and event management on the completed project. LUMS may also need to be considered on freeways with emergency stopping lanes (ESL) where high volumes throughout the day increase the crash risk.

5.2.2 Enhanced traveller information and network intelligence

Freeway mainline VMS shall be incorporated on Smart Freeways for an enhanced level of en-route traveller information. VMS play an important part in managing traffic through use of real-time travel-time and freeway condition information that may influence route choice.

Freeway-to-freeway VMS (RC3-C) shall generally be incorporated on Smart Freeways for an enhanced level of off-route traveller information. VMS play an important part in managing traffic through use of real-time travel-time and freeway condition information that may influence route choice.

A Smart Freeway requires greater network intelligence such as vehicle detection systems and CCTV cameras to support the operation of the control and information systems.

Table 5.2 Smart Freeways higher-order ITS requirements

ITS Technology	Warrants and approval guidelines	Section
Ramp signals	• Coordinated ramp signals (including freeway-to-freeway ramps and ramps entering as an added lane) shall be provided as a route treatment • Coordinated ramp signals for retrofitting an existing freeway are appropriate if: ○ flow breakdown is occurring at several 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). • For a freeway upgrade or new freeway project, a freeway design volume / design capacity analysis according to Victoria's MMDG Volume 2: Part 3 shall be conducted to determine the number and extent of entry ramps required as part of the system. In some cases, additional upstream and/or downstream ramps may be required for ramp signalling to ensure effective control of the freeway corridor, e.g. critical bottlenecks, and to prevent the bottleneck being displaced downstream, and hence causing congested traffic from outside the project to queue back into the project area. See warrants above and in Section 6.2 • Isolated ramp signals shall only be considered to address localised issues if route design volume / design capacity analysis demonstrates they will operate satisfactorily, i.e. upstream ramps are not contributing to the problem and the downstream ramps are also operating satisfactorily. • Entry ramps not needing initial provision of ramp signalling shall be designed for future implementation of CRS. See Section 6.2 for further guidance and numerical warrants.	6.2
Priority vehicle facilities	Priority access at entry ramps using priority lanes may be considered in the following situations where there is a strategic need: • Access points from major industrial and commercial areas • Along identified freight corridors or routes (e.g. the principal freight network) • Ramps which form part of a public transport bus route. Priority lanes with ramp signals shall be metered to assist in managing the mainline and preventing flow breakdown. Generally, mid-block priority lanes on freeway sections shall not be provided on Smart Freeways as they adversely affect the productivity of the freeway, due to under-utilisation of the priority lane.	6.2.3
Variable speed limits (VSL)	VSL shall be provided as a route treatment as part of a lane use management system (LUMS) or where there is a need to manage speed due to environmental factors or the prevalence of congestion. VSL may be considered for implementation in the following situations: • As part of a LUMS environment where integrated use of lane control signals for both speed and lane use management are provided • As a safety treatment for serious crash sections, or as a crash preventative measure to lower the speed limit to match operating speeds during congestion, including back of queue protection – noting that the deployment of CRS will reduce the occurrence of peak period and congestion-related crashes and, as such, VSL would only be required as an additional intervention to CRS • Where appropriate ramp signal design cannot be achieved due to geometric constraints (e.g. within the CBD). This is not desirable practice and shall only be considered under the extended design domain process.	6.4

ITS Technology	Warrants and approval guidelines	Section
Lane use management systems (LUMS)	• LUMS shall be provided to enable all lane running (ALR) as a route-based treatment (see Section 6.5.2) when required to provide additional physical capacity and it is not practically, economically or politically feasible to undertake significant geometric improvements or civil upgrades. • LUMS may be considered for heavily trafficked freeways in the order of 17,000 veh/day/lane or more (one-way) that include full time use of emergency stopping lanes or shoulder, i.e. non-ALR. This form of traffic management may be appropriate where: ○ there are more than three through-traffic lanes, except in tunnels ○ the cost of LUMS provision if an incident occurs, provides benefits for high-traffic volumes over extended periods of the day ○ a safer level of control is needed due to recurrent incidents, e.g. due to inadequate mainline control, recurrent congestion or the complexity of traffic movements ○ a higher level of efficiency is needed to manage incidents and hence minimise disruption time and impact to traffic flow, e.g. along critical segments of the freeway network or where alternative routes may not be available for traffic diversion ○ dynamic opening or closing of the shoulder is required for traffic management needs ○ adjacent sections of freeway that have LUMS or VSL operations need to be connected. • LUMS signs that integrate VSL shall be used unless it is not feasible due to space restrictions, e.g. in a tunnel, in which case separate lane control signals and side-mounted VSL signs may be used.	6.5
All lane running (ALR)	• ALR may need to be considered where further widening of the freeway is not feasible to increase the capacity of the freeway. ALR may need to be considered for deployment as a route treatment when required to provide additional 'physical' capacity and it is not practicable, or not economically, environmentally or politically feasible to undertake significant geometric improvements or civil upgrades. • It is not appropriate to use ALR as an interim short-term solution, before widening can take place. • Where ALR is being suggested, proposals will be considered under the extended design domain process (see the Main Roads' Smart Freeways Policy Framework Overview).	6.5.2
Automated incident detection (AID)	AID (including stopped vehicle detection) may be considered to improve road safety, incident detection and response times. Any freeway with higher order ITS would benefit, in particular at the following freeway locations: ○ Complex segments of the freeway and particularly sections with ALR ○ Freeway-to-freeway interchanges ○ Key bottleneck areas where flow breakdown is a significant risk ○ Sections with a higher exposure and risk of incidents, e.g. heavy traffic flows throughout the day ○ Sections where there is no, or reduced width, of the emergency lane, e.g. tunnels, bridges.	8.6
Freeway VMS	• Mainline VMS at a spacing of 3 km to 5 km should be deployed on the mainline, subject to spacing of significant interchanges and the presence of a LUMS environment. • Priority should be given to deployment in advance of LUMS environments, major decision points such as exit ramps 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.	7.1

ITS Technology	Warrants and approval guidelines	Section
Tactical VMS	• Tactical VMS shall be considered on the mainline within a LUMS environment according to the VMS Guidelines.	7.3
Freeway-to-freeway VMS (RC3-C)	• Shall be provided in advance of freeway-to-freeway interchanges, particularly where traffic data, i.e. VDS, are available on the intersecting freeway and/or alternative routes are available for trip diversion. • Essential where ramp signals are provided on a freeway-to-freeway ramp.	7.4
Arterial road VMS (RC3-A and RC3-B)	• Arterial road VMS (RC3) shall be provided at all entry ramps with ramp signals according to Main Roads' guideline drawings and Victoria's MMDG Volume 2, Part 3, including the Main Roads' Supplement. • RC3 signs may be considered at unmetered ramps with a high traffic movement from the arterial road to the freeway (peak ramp flow ≥ 600 veh/h). • Arterial road VMS may be considered 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.	7.5
Vehicle detection systems	Vehicle sensors shall be deployed for lane data on the freeway mainline, at interchanges (including entry and exit ramps) and other locations as required for operation of freeway control. For locations and spacing, see the Main Roads' Supplement, Guideline Drawings and Victoria's MMDG Volume 2, Part 3.	8.1
CCTV cameras (incident verification)	CCTV cameras shall provide full and unobscured coverage of the freeway with spacing at typically 1 km for straight alignments or more frequently for complex sections with curved alignments. Overlapping coverage shall be provided for sections of freeway with ALR, LUMS, or complex areas with lane changing or heavy traffic throughout most of the day, i.e. where there may be a greater exposure risk to incidents.	8.2
Emergency stopping bays and roadside help phones	Deployment shall be as per Main Roads' Guideline: Emergency Stopping Bays and Roadside Help Phones.	8.4
Travel-time algorithms	These shall be provided to support real-time travel-time information via roadside VMS or pre-trip and in-car services, as well as freeway performance evaluation.	8.5
Other systems	Other ITS devices or systems according to project-specific needs, e.g. high winds or flood warning may need to be deployed.	6, 7, 8

6 Traffic management and control technologies

6.1 Overview

Smart Freeway control options shall be considered for deployment on existing, upgraded or proposed freeways according to the guidance below, or where there is recurrent flow breakdown and congestion due to high traffic demand. An indicator of recurrent congestion is when average peak period travel speeds for a corridor are approximately 60 per cent or less than the posted speed limit.

6.2 Coordinated ramp signals (CRS)

CRS are traffic signals provided on entry ramps to control access to the freeway in a measured and regulated manner in order to manage the freeway traffic flow (see Figure 2-1).

In a well-designed and operated system, ramp signals can generally prevent flow breakdown and congestion, or at least delay flow breakdown in other circumstances. Ramp signals can operate under either isolated or coordinated levels of control and are applied to all ramps required to effectively manage the freeway corridor, including freeway-to-freeway entry ramps (see Section 6.2.2).

To address a localised mainline merge problem, it may be solvable by a localised ramp signals installation (see Section 6.2.1). However, on a heavily trafficked freeway network the extent of freeway problems generally result from widespread traffic demands and require a coordinated system.

Victoria's Managed Motorways Design Guide (MMDG): Volume 2 Part 2 (2019) provides an overview of ramp signals operation and benefits. The MMDG: Volume 2 Part 3 provides planning and detailed design guidance on ramp signalling, including the minimum requirements for other supporting ITS devices and systems providing network intelligence and traveller information functions. These guides are to be read in conjunction with the Main Roads' Supplement (2020).

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 regulates the entry of traffic from 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 critical bottlenecks downstream.

CRS help to maintain the critical occupancy (density) of the freeway mainline and reduce the possibility of flow breakdown through the following principal actions:

- Managing the headway of entering traffic at each ramp, i.e. providing an evenly distributed flow of traffic into the merge area.
- Managing the flow rate of entering traffic at each ramp when the merge is near capacity, i.e. limiting the entry flows to avoid transition to an unstable condition in the merge area.

- In a coordinated manner, ensuring the stability of the overall mainline freeway corridor and that the freeway volume does not exceed the bottleneck capacities, particularly at critical bottlenecks, i.e. to prevent or delay flow breakdown.

In all above aspects of operation, ramp signals can increase capacity when compared with unmanaged operation. CRS also can restore the traffic flow faster in case of flow breakdown due to an unplanned event such as a traffic incident.

Warrants

CRS shall be implemented as a corridor-wide adaptive system for Smart Freeways where the peak direction mainline design volume (see Section 4.1.2), forecast at the estimated date of project completion is ≥ 90 per cent of the applicable maximum sustainable flow rate (MSFR) for unmanaged freeways design (see Table 7.3 of Victoria's MMDG Volume 2 Part 3). See Figure 6-1 for a two-lane example showing flow breakdown risk.

The MSFR values, and hence the CRS warrant, varies according to the number of lanes, grade and proportion of trucks, due to the flow effects of these factors on capacity. For relatively flat grades, i.e. ≤ two per cent, these values generally equate to:

- 3,200 pc/h for two-lane carriageways
- 4,640 pc/h for three-lane carriageways
- 5,960 pc/h for four-lane carriageways, and
- 7,090 pc/h for five-lane carriageways.

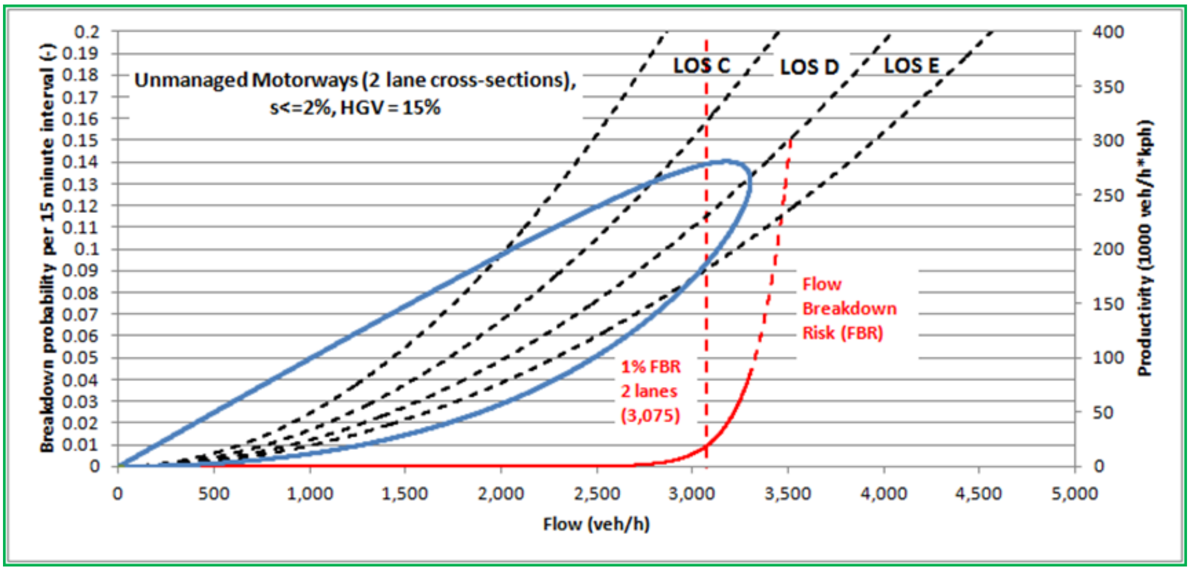

Figure 6-1 Example of flow breakdown risk relative to flow rate (two-lane carriageway)

Source: VicRoads (MMDG Volume 1, Part 3)

The warrant applies to any point along the freeway (between or within interchanges), as well as downstream sections of freeway where mainline volumes will increase, based on the worst-case design volumes (either the AM or PM peak period). This may mean ramp signals being provided outside the 'formal' project boundaries to manage the mainline traffic along the freeway corridor.

Where a route meets the warrants (existing, upgraded or proposed freeway), the extent of the coordinated ramp signal system is determined by mainline analysis based on forecast design volumes. This includes consideration of control downstream, as well as the upstream partially managed transition zone (PMTZ) as outlined in the MMDG Volume 2, Part 3 Sections 4.4.5 and 4.4.6.

The need to provide ramp signals applies to all entry ramps including freeway-to-freeway ramps, ramps leading to added lanes, collector distributor roads entering the mainline and low-flow ramps (which may include service centres on freeways with high demand relative to capacity).

The warrants for provision of ramp metering signals are based on several factors documented in the MMDG including:

- The probabilistic, rather than a deterministic, nature of flow breakdown on freeways that are uninterrupted traffic facilities. The nature of flow breakdown is consistent with probability of flow breakdown research indicating that reaching capacity flows is not a prerequisite for flow breakdown, and that clusters of vehicles from a ramp, rather than ramp flow, affect the freeway operation at the ramp merge and other bottlenecks.
- Safety investigations relating to freeways with free flowing, and unstable or congested traffic conditions.
- The objective of preventing flow breakdown, even at low levels of probability, given the impact that this can have on safety, throughput, efficiency (travel speed) and productivity. From a route perspective, capacity changes along the mainline are frequently contributing factors to flow breakdown.
- At mainline flows meeting the warrant, entry ramp flows are also significant.

In addition, for retrofitting existing freeways CRS are required where:

- congestion and flow breakdown are already occurring at one, or several bottlenecks over a length of freeway, and
- flow breakdown occurring at a location cannot be addressed by an isolated ramp signal, i.e. freeway flow causing the flow breakdown results from a combination of several upstream entry ramps.

In a route-based approach with CRS, which is generally required on heavily trafficked freeways, even individual entry ramps where the mainline merge does not meet the criteria for ramp signals requires metering to provide sufficient control of the freeway sections where recurrent flow breakdown is occurring.

Generally, if a well-designed coordinated system is not provided, then access equity, i.e. balancing of queues across ramps, efficient utilisation of available ramp storages and effective control of the freeway flow cannot be achieved. 'Rat-running behaviour' where motorists choose ramps with no signals may also occur.

Determining how many ramps are required for metering depends on the outcomes of the freeway traffic analysis based on the MMDG Volume 2: Part 3 Sections 4.3 and 4.4:

- For concept level assessment see the MMDG Volume 2: Part 3, Section 4.4.5.2.
- For detailed design assessment see the MMDG Volume 2: Part 3, Section 4.4.5.3.

At some locations, it may be necessary to interface the ramp signals and the arterial traffic signals for optimal operation of the entire road network. For example, if relatively long ramp queues are expected, 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 longer phase.

Integration with traffic signals is also required where there are physical constraints on ramp storage capacity that cannot be overcome during design and arterial roads need to have additional queue storage.

Benefits for the freeway network

The benefits of coordinated ramp signals in a well-designed and operated system are documented in the MMDG Volume 2: Part 2, Chapter 6. These include quantitative and qualitative benefits for traffic throughput, travel time and safety.

Benefits for the broader arterial road network

Research and modelling show that when a freeway is operating at high efficiency and productivity, the broader arterial road network will also benefit (see MMDG Volume 2: Part 2, Chapter 6).

Technology and installation configurations

The core component of coordinated ramp signals is the control system and algorithms that manage the mainline traffic and traffic entering the freeway. The range of equipment and locations required for effective operation of the ramp signals are provided in the MMDG Volume 2 Part 3 and the Main Roads' Supplement. They include:

- signal controller
- traffic signals and the signal support pedestals
- ramp signalling fixed regulatory and other signs as well as pavement markings
- 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 sensors on the mainline and entry ramps, as well as the arterial roads when used for ramp storage (see below for further detail)
- VMS (RC1, RC2 and RC3) (see Section 7 for further detail), and
- power and communications infrastructure and lighting, see Main Roads' standards where appropriate.

In regard to detailed design guidance (including geometric layouts), see Victoria's Managed Motorways Design Guide: Volume 2 Part 3 (2019), the Main Roads' Supplement to the MMDG (2020), and the Main Roads' Smart Freeways Variable Message Signs Guidelines (2020).

6.2.1 Isolated ramp signals

While coordinated ramp signals as a route treatment are generally needed to manage demand on heavily trafficked freeways, there may be locations where isolated ramp signals can provide headway management of ramp traffic and flow-rate control when the merge is near capacity.

Isolated ramp signals operate independently and do not interact with other entry ramps. They are only effective at a ramp where entering traffic causes flow breakdown in the mainline flow at the ramp merge, and where there is no traffic impact on, or from, other interchanges. Their function is to manage the entering rate of traffic to overcome the impact of uncontrolled platoons of traffic entering the freeway. Operation shall be dynamic and controlled by the ramp signals system.

Warrants

Isolated ramp signals may be effective in reducing merging problems and improving freeway traffic flow where there is an isolated high merging flow. However, they have limited functionality and ability to balance operation along a route. Only consider isolated ramp signals when analysis of existing or forecast flows (as appropriate) indicates that:

- breakdown of the mainline flow is localised and clearly only associated with platoons of traffic entering at a particular ramp
- localised mainline flow is unrelated to upstream entry flows arriving at the site, with flows within the appropriate maximum sustainable flow rate (MSFR) for an unmanaged freeway, i.e. warrant being 90 per cent of the appropriate unmanaged MSFR (see Section 5.2, and Victoria's Managed Motorways Design Guide: Volume 2: Part 3 (2019)
- the local ramp flow does not contribute to downstream flow breakdown or congestion
- where a high number of peak-period, congestion-related crashes are occurring, i.e. rear-end, sideswipe and lane-changing crashes, and
- redistribution of traffic to other adjacent ramps is unlikely or negligible.

6.2.2 Freeway-to-freeway ramp signals

Freeway-to-freeway ramp signalling is generally required as part of a coordinated system to provide control of traffic flows downstream. This is particularly important if there is limited ability to control traffic upstream of the interchange.

Victoria's Managed Motorways Design Guide: Volume 2 Part 3, Chapter 7 (2019) provides detailed guidance for consideration of ramp signals at freeway-to-freeway ramps. Depending on the nature of the interchange, different approaches may be appropriate.

Generally, to manage mainline traffic flow at a bottleneck, or a series of bottlenecks over a long distance, i.e. not just at the freeway ramp, all upstream entry flows need to be controlled, including freeway-to-freeway ramps, even if they enter into an added lane(s). If flow breakdown does occur on the Smart Freeway this would impact not only the Smart Freeway but also the traffic from the entering freeway.

Where freeway-to-freeway ramp signalling is provided it would only operate when needed, and uninterrupted free-flow entry would be available at other times.

Notes:

1. For freeway-to-freeway ramps with volumes approaching the maximum in Table 6.1 of Victoria's MMDG Volume 2 Part 3, (i.e. volumes in the range 2,500 veh/h to 3,000 veh/h), Section 6.2.1 (Controlling Very High Ramp Flows) of the guide may be relevant.

2. It may also be possible to use VSL to assist ramp signals in controlling a freeway-to-freeway interchange, but this would be less effective than controlling the flow with ramp signals. Further research is being undertaken to develop the appropriate algorithms.

Warrants

The requirement for ramp signals to control freeway-to-freeway movements shall be based on detailed analysis of design flows at the interchange, and along the route as a whole, in accordance with Victoria's MMDG Volume 2 Part 3, Sections 4.3 and 4.4.

Where consideration is being given to an uncontrolled freeway-to-freeway ramp, the route design performance shall be shown as acceptable based on analysis as an unmanaged entry (using unmanaged MSFR) as well as the downstream sections of freeway being partially managed (see Section 4.4.5 of Victoria's MMDG Volume 2 Part 3).

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

6.2.3 Priority vehicle facilities

Due to the economic importance of moving freight as well as the strategic advantages of promoting efficient public transport, there can be advantages in providing special facilities for priority vehicles.

Priority or high-value vehicles that can be given specific consideration may include public transport vehicles, freight (trucks with a GVM of 4.5 tonnes or more), high occupancy vehicles (T2 / T3) and taxis. While emergency vehicles are also priority vehicles, they do not need specific design provisions as they can be managed directly into a controlled Smart Freeway by switching off the ramp signalling to clear the queue on the ramp needing to be used.

Mid-block priority lanes on freeway sections are used in some jurisdictions to allow permanent or dynamic access (i.e. during peak hours) to high-value vehicles. Generally, these shall not be provided on Smart Freeways as they adversely affect the productivity of the freeway, due to low use of available pavement, and other capacity implications due to lane changing, etc (see Victoria's Managed Motorway Design Guide Volume 2: Part 3 Section 4.3.2.11).

In the context of managing mainline flow, priority lanes at entry ramps with ramp signals shall be controlled. The priority vehicle access advantage is provided with a shorter queue relative to other general traffic.

Warrants

Priority access at entry ramps may be considered using priority lanes in the following situations where there is a strategic need:

- access points from major industrial and commercial areas
- along identified freight corridors or routes (e.g. the strategic freight network), and
- ramps that form part of a bus route.

The Main Roads' Smart Freeways Policy Framework Overview (2020) provides further guidance of potential locations for priority access of trucks. This does not mean that a separate priority access lane is feasible nor should be provided, as all proposals need to be considered case-by-case according to their merits.

The below treatments shall only be considered under the extended design domain process:

- Providing a free-flow priority access lane. Generally, this is inappropriate due to the potential for bunching of priority vehicles such as trucks, which may trigger flow breakdown at the ramp entry to the mainline, as well as an inability to manage overall traffic at downstream bottlenecks. Only consider uncontrolled free flow bypass lanes for trucks and/or buses and when there is an added lane, or if detailed forecast design volume / MSFR capacity analysis demonstrates there are no critical bottlenecks within three to four downstream sections of the freeway.
- Priority access for high occupancy vehicles (T2 / T3). Generally, this is inappropriate due to the potential for abuse and non-compliance in a situation where enforcement is generally not practicable.
- Providing a queue-jump lane for public transport buses where the entry ramp is part of a bus route. This will be subject to an appropriate design layout.

Technology, design and installation configurations

For entry ramps with a high proportion of trucks (shared lane use and no separate lane for trucks), it may be possible to improve geometric design for trucks, such as providing longer acceleration distances. However, the operation of ramp signals in Melbourne demonstrates that normal acceleration lengths have operated satisfactorily, including for trucks.

If a priority access lane is provided, the preferred layout has a significant length for acceleration and merging. See the Main Roads' Supplement to Victoria's Managed Motorway Design Guide: Volume 2, Part 3 for design detail relating to layout options.

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

6.3 Arterial road traffic signals interface

The traffic signals operated through SCATS (Sydney Coordinated Adaptive Traffic System) have adaptive timing and coordination of traffic signals. Traffic signals at interchange intersections may need to be integrated with the freeway operations, particularly in relation to CRS operation if an entry ramp has less than desirable storage, or if an exit ramp storage is inadequate, to prevent exit ramp queues affecting mainline operation.

Warrants

Interfacing between the coordinated ramp signal system and SCATS that enable adjustments to the traffic signals operation should be considered to integrate entry and exit ramp controls in the following situations:

- Managing entry ramp queues where the arterial road is used for queue storage.
- Managing entry ramp access where the entry ramp has less than desirable storage.
- Managing exit ramp queuing that extends back to the freeway, i.e. at ramps with inadequate length and/or high exit volumes.
- Controlling traffic at the end of freeways to manage intersections and freeway queues.
- Accessing control onto the freeway in case of ramp and freeway closures, e.g. to prevent turn phases into the entry ramp, etc.

Technology and installation configurations

Additional vehicle sensors should be installed consistent with the interfacing and system operations.

6.4 Variable speed limits (VSL)

VSL are used to improve road safety of traffic flow by displaying appropriate speed limits for varying freeway traffic conditions on VSL signs.

In the Smart Freeways context, the main applications of VSL are for:

- Incident and event management (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 are used in conjunction with LUMS (see Section 6.5) to reduce speeds for lane closures or when passing through roadworks (includes maintenance) or incident location. Reduced speeds help to protect road users and provide a safer working environment for road workers and incident responders at the affected road sections.
- Integration with AID for congestion and queue protection – used to improve safety by managing speeds during congestion, and to slow down vehicles ahead of congestion caused by high demand or incidents. It regulates speed and also warns motorists on approach to the congestion to reduce the risk of high-speed traffic encountering the queue. As a result it also reduces the likelihood of secondary incidents, particularly rear-end crashes.

- Responding to environmental conditions – speed limits can be adjusted to improve road safety for vulnerable road sections, including bridges or on the approach to tunnels during adverse weather conditions, e.g. heavy rain, fog or high wind speeds.
- Integration with CRS – to optimise traffic flow (still under research and development).

Victoria's Managed Motorways Design Guide (MMDG): Volume 2 Part 4 (2020) provides an overview of benefits, operation and design associated with variable speed limits (VSL). Relevant sections in this guide shall be read in conjunction with the Main Roads' Supplement (2020).

VicRoads undertook a review of international research on the effectiveness of VSL (VicRoads 2012) as well a summary of benefits in Victoria's Handbook for LUMS, Variable Speed Limits and Traveller Information (2013).

The reviews found that VSL can improve safety and reduce the frequency of shockwaves (presumably in congested conditions). While VSL may also reduce the probability of flow breakdown, research was inconclusive on whether it could also deliver capacity and traffic flow benefits. However, benefits may be 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, and/or by mainline metering, such as holding back mainline traffic to support CRS operation. In addition, traffic flow benefits are achieved through reductions in secondary incidents as a result of queue protection.

The reviews also highlighted that VSL are generally considered to delay rather than prevent the onset of congestion and that the timing of VSL activation is critical otherwise adverse effects can occur. Also, many studies demonstrating benefits are for high speed (>110 km/h) or rural motorways and the applicability to Australian freeways is questionable as freeway speed limits are generally 100km/h or less and have a high level of enforcement. These factors effectively homogenise speeds and reduce speed differentials, so further benefits shown in higher-speed international environments may not be relevant.

The conclusion is that on heavily trafficked freeways the use of VSL alone is ineffective in preventing flow breakdown as it cannot manage or control demand at critical bottleneck locations. The Smart Freeway deployment of CRS provides superior management of traffic flow, significant improvement in safety, and reduced congestion-related incidents. VSL-integrated operation is being considered in Victoria to support the operation of CRS as modelling and an initial on-road trial are promising. However, further development of operational algorithms is needed.

Warrants

The integrated use of VSL and lane use signals for both speed and lane use management is always part of a LUMS environment. VSL as a route treatment shall be investigated where there is a need to manage speed due to environmental factors, or the high likelihood of congestion.

VSL should be considered in the following situations:

- As a safety treatment for serious crash sections, e.g. high rates of non-congestion-related incidents. Deploying CRS will significantly reduce the occurrence of congestion-related incidents and, as such, VSL is only required as an additional intervention to CRS to improve safety and/or ability to manage flow.
- 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 help with managing events where traffic management is frequently used for planned events, e.g. abnormal-sized load escorts, sporting events and road works.
- For consistent route speed management along a length of freeway, e.g. as a lower cost treatment between adjacent sections of LUMS.

Technology and installation configurations

Variable speed limits are communicated to road users through electronic signs that display the mandatory speed limit. VSL signs shall comply with the format and colours indicated for LUMS and VSL signs in the Smart Freeways Supplement for design of LUMS and VSL. Signs need functionality to show three numbers (Figure 6-2). Main Roads recommend consideration of flashing part of the VSL signs annulus or use flashing yellow conspicuity lanterns for older signs during operations when the signs display speeds lower than the default speed limit if the reduced speed limit is not likely to be immediately apparent to the approaching driver.

Figure 6-2 Example of side mounted VSL sign

Where VSL is part of a Smart Freeway project signs shall be installed according to requirements in the Main Roads' Supplement to Victoria's design guide for LUMS and VSL.

Where overhead signs are recommended for either LUMS or VSL, integrated LUMS signs shall be used due to improved functionality at marginal additional cost. Where VSL is integrated with LUMS, a speed limit above the road indicates that the lane is available.

In tunnels, integrated LUMS signs (VSL and lane use signals) is also preferred for consistent traffic management control and appearance along the freeway. However, if due to vertical clearance, overhead signs or use of LUMS signs is restricted, side-mounted VSL signs may be considered.

Longitudinal spacing of VSL on the mainline shall be in accordance with the requirements for LUMS gantries (see Section 6.5.2 and Main Roads' Supplement to Victoria's design guide for LUMS and VSL).

For a section of freeway with VSL in operation, VSL signs shall be installed on the entry ramps, generally side-mounted in accordance with Main Roads' guideline drawings, and in conjunction with the MR-GE-22 (start of freeway) supplementary sign. When used at entry ramps with ramp signals, they shall be located downstream of the ramp signals in accordance with Main Roads' guideline drawings. The VSL signs facing the ramp traffic may be also located overhead, e.g. where desirable to suit the location of a LUMS gantry that also spans the ramp.

6.5 Lane use management systems (LUMS)

Traffic incidents result in significant traffic flow, safety, economic, social and environmental impacts, so incident management strategies and an effective incident management system are important to minimise these impacts. Early identification and effective management of an incident, as well as initiation of actions to reduce freeway demand, can also help minimise the impact on traffic flow, plus improve safety and help prevent secondary incidents.

LUMS can be deployed to provide traffic management and improve safety during incidents, road works and events. They can divert traffic around an incident or event, provide safe access for incident responders (including emergency services and road workers), to protect the affected location and/or to direct traffic off the freeway if it needs to be closed. This also reduces the likelihood of secondary incidents.

LUMS allocate and manage lane use across the carriageway. Electronic LUMS signs indicate the status of the lanes to road users, including lanes open (displaying the speed limit), lane change (angled arrow) and lanes closed (red cross). Austroads (2016) defines LUMS as including variable speed limits, and refers to electronic signs within LUMS as 'LUMS signs' that have capability to display both VSL and lane control signals (LCS). Other guidelines may refer to LUMS signs as VSL/LCS or lane use signs (LUS).

Victoria's Main Roads' Supplement to Victoria's design guide for LUMS and VSL provides an overview of benefits, operation and design associated with a lane use management system (LUMS). Relevant sections in this guide, including guidelines for installation, are to be read in conjunction with the Main Roads' Supplement (2020).

While LUMS are used specifically for incident and event management, in other cases they may be used to implement operational strategies to achieve capacity improvements through dynamic use of the full pavement, including ALR. They can also be used to support reversible lane systems, generally with a moveable barrier for freeway applications. Further guidance and warrants for each of these applications are described in the following sub-sections.

An integrated system with lane use and VSL enables the operators to manage the traffic flow in a clear and efficient way, for example through using both lane closures and reduced speed limits to direct traffic safely around an incident. Although integrated LUMS signs are also desirable in tunnels, there may be limitations due to ceiling height restrictions.

LUMS automatically controls the operation of the LUMS signs through traffic management rules, which are also combined with the operation of variable speed limit displays. Typical LUMS symbols are shown in Figure 6-3.

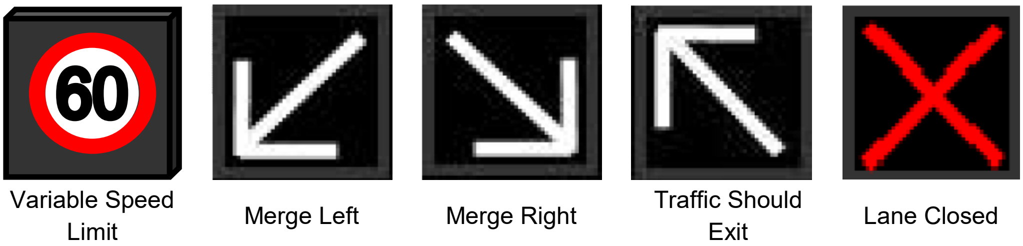

Figure 6-3: LUMS displays

6.5.1 General use for incident and event management

The general application of LUMS for incident and event management may include heavily trafficked freeway sections that include emergency stopping lanes or shoulders. This form of traffic management may be appropriate:

- where LUMS provides benefits for high traffic volumes over extended periods of the day
- where a safer level of control is needed during incidents due to, e.g. inadequate mainline control, recurrent congestion or the complexity of traffic movements
- where a higher level of efficiency is needed to manage incidents and hence minimise disruption to traffic flow along critical segments of the freeway network or where alternative routes are not available for traffic diversion
- where dynamic opening or closing of the shoulder is required for particular traffic management needs
- to connect adjacent sections of freeway that have LUMS or VSL operations, to maintain continuity of traffic control, and
- to help manage speed and to improve road safety in the following situations:
  - people attending roadside emergencies, i.e. 'Slow Down, Move Over' (SLOMO) operation. The law requires motorists to reduce speed to a maximum of 40km/h when passing incident response vehicles with flashing lights on and, where possible and safe to do so, move to the next lane
  - when a road user is leaving an emergency stopping bay.

Warrants

LUMS for deployment on freeway sections with emergency stopping lanes or shoulders should be considered where:

- there are more than three through-traffic lanes, except in tunnels, i.e. heavily trafficked freeways
- performance outcomes for incident management require the freeway to be restored to full operations within the shortest manageable timeframes due to the critical nature of the freeway segment in the network
- high traffic volumes occur throughout the day (not just at peak periods)
- there are additional safety risks that could be reduced by lane use management, e.g. high-density traffic on a wide pavement where a vehicle may have difficulty reaching the shoulder

- there are high rates of incidents due to congestion or other reasons – noting that LUMS is not effective for congestion management as this is better addressed with a well-designed and operated CRS system
- traffic management is frequently provided for planned events, e.g. abnormal-sized load escorts, sporting events
- there needs to be consistent route management along the freeway, e.g. to connect LUMS on adjacent or connecting freeway segments.

Technology and installation configurations

The LUMS signs shall be centrally mounted over each lane on gantries, side-mounted cantilever structures or overhead bridges. Gantries may span each carriageway or the full width of the freeway depending on the location-specific context.

Reference shall be made to Victoria's design guide for LUMS and VSL as well as Main Roads' Supplement information for guidance on mainline longitudinal spacing of LUMS gantries near interchanges, and between interchanges, as well as spacing relative to other signs and traffic management devices.

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

For a section of freeway with LUMS, VSL signs shall be installed on the entry ramps, generally side-mounted in accordance with Main Roads' guideline drawings, and in conjunction with the MR-GE-22 (start of freeway) supplementary sign. When used at entry ramps with ramp signals, they shall be located downstream of the ramp signals in accordance with Main Roads' guideline drawings. The VSL signs facing the ramp traffic may be also located overhead, e.g. where desirable to suit the location of a LUMS gantry that also spans the ramp.

6.5.2 All lane running (ALR)

ALR occurs when the full width of the pavement is permanently used, and no ESL or shoulder is available. In an upgrade project, this may involve the conversion of the emergency stopping lane (shoulder) to a permanent running lane, or it may be a freeway segment constructed without an emergency lane due to design constraints and/or cost. This freeway geometry effectively provides an additional running lane to increase the capacity of the freeway.

When ALR is provided for extensive lengths it shall incorporate LUMS gantries and signs (unless otherwise approved as part of the extended design domain process).

ALR over short distances i.e. lengths not needing LUMS or speed limit reduction (see installation configurations guidance below) may be considered in the following situations as a localised treatment:

- between interchanges, i.e. an auxiliary lane to provide additional capacity for lane changing or weaving and/or to minimise the need for drivers to interact with the mainline through traffic flow
- on bridges where widening may not be feasible at reasonable cost

- at short exit ramps, i.e. by providing extended exit lane storage to prevent queues extending back to the freeway mainline, or where it is not feasible to extend the ramp length.

Warrants

Where further widening of the freeway is not feasible, ALR may need to be considered for deployment over a significant distance as a route treatment, when required. This will provide additional 'physical' capacity where it is not practicable, or not economically, environmentally or politically feasible to undertake significant geometric improvements or civil upgrades.

The use of ALR as an interim short-term solution before widening can take place, is generally inappropriate. This impacts safety (due to no ESL) and efficiency (increased travel time due to lower speed limit), and due to lower than normal speed limits, high levels of non-compliance, hence greater speed differentials. Where this is being suggested, consider proposals under the extended design domain process (see Main Roads' Smart Freeways Policy Framework Overview). ALR is not a convenient alternative to a better solution.

Where further widening of the freeway is not feasible, ALR may be considered on Smart Freeway sections if the capacity assessment for peak period forecast design volumes indicates that it is necessary according to Victoria's MMDG Volume 2, Part 3 Sections 4.3 and 4.4.

Technology and installation configurations

For ALR, all trafficked lanes need to meet at least the minimum requirements for a running lane. This may require upgrades of pavement strength, surface treatments, verge treatments, drainage, fixed signage and lane marking. Reduced lane widths may be considered for constrained sites where 3.5 metre lane widths cannot be accommodated. This may however, require a lower default speed limit. Where this is being suggested, consider proposals under the extended design domain process (see Main Roads' Smart Freeways Policy Framework Overview).

The following key principles apply when designing freeways with ALR:

- Provision of CRS is required to optimise safety, throughput and productivity.
- Provision of LUMS gantries and signs to manage lane use and speed is required on ALR segments in the order of 2,000 metres long for a four-lane carriageway. This is generally based on a minimum number of LUMS gantries necessary to manage lane use, i.e. lane closures, with a typical spacing of 500 metres and sequential lane reductions. Over this distance it is noted that there will only be limited control and upstream VMS will also be essential. Shorter distances are applicable for ALR in tunnels.
- Provision of emergency stopping bays and roadside help phones at regular intervals according to Main Roads' Guideline for Emergency Stopping Bays and Roadside Help Phones.
- Enhanced surveillance and monitoring, including:
    - overlapping CCTV coverage, including at all emergency stopping bays and any areas under bridges or other structures
    - vehicle detection for all emergency stopping bays

    - AID with a high level of intervention in the event of incidents and vehicle breakdowns
- Provision of traveller information prior to and throughout the ALR segments (see Main Roads' Variable Message Signs Guidelines (2020).

The requirements above not only improve safety but also reduce the risk of secondary incidents, particularly rear-end crashes.

Other LUMS technology and installation requirements and functionality are the same as those outlined above in Section 6.5.1.

6.5.3 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 use 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, and
- to assist with traffic management during road works including maintenance of infrastructure such as bridges and ITS field equipment.

LUMS and moveable central barriers are usually required to implement reversible lane systems.

Warrants

Reversible lane systems can be considered for situations where:

- tidal flow patterns are observed (e.g. where over 70 per cent of peak traffic travels in one direction), and
- a reduced number of lanes (minimum two 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 the two existing carriageways, e.g. along the median.

Separation systems between directional flows shall comply with Main Roads' Safe Systems requirements and road safety barrier guidelines. Lane use instructions shall be reinforced through LUMS, variable message signs and fixed signs. In addition, for 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. Follow documented operating procedures before opening and closing the reversible lane arrangement.

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 6.5.2.

6.6 Compliance and enforcement

The traffic control interventions installed in Smart Freeways imply a new driving experience for motorists. It is therefore essential that Smart Freeways provide an intuitive and self-compliant driving environment. A focus on driver education as opposed to enforcement, particularly in the initial period, will help drivers accept new technologies.

However, Smart Freeways may need to be designed with consideration for future requirements for enforcement. Possible enforcement measures include compliance of mandatory speed limits through VSL signs and lane closures displayed through LUMS, e.g. the red diagonal cross. In regard to speed compliance, 'point-to-point' enforcement is generally preferable, as single-point speed cameras can cause road users to slow down unnecessarily (and sometimes quickly to a speed that may be significantly less than the speed limit), creating a trigger and potential for flow breakdown which could impact the freeway corridor as a whole.

In regards to ramp signals, non-compliance may sometimes occur when the signals first switch on. However, after the queue starts to develop there is generally good compliance as road users are already at the head of the queue, and there is limited advantage in driving through the red light. Compliance reports from the ramp signals system may not be reliable as data may include road users that are slow responding to the green signal. Generally, occasional non-compliance at ramp signalling does not result in a safety risk. Therefore, enforcement should only be considered when the observed compliance levels are problematic.

In regards to priority access lanes, compliance issues may include non-conforming vehicle types using the priority lane. Controlling the priority lane with ramp signals as required in Section 6.2.3 (compared with free-flow bypass which is undesirable), generally reduces the extent of non-compliance.

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

Warrants

Enforcement interventions may need to be considered for safety reasons where there are compliance problems to improve driver behaviour. It is important to design for an intuitive and self-compliant driving environment and encourage compliance through educational efforts.

Nevertheless, design of the freeway may need to allow for future implementation of field equipment, control systems and other relevant measures, e.g. enforcement stopping bays to support enforcement. These devices shall align with Main Roads and WAPOL systems.

7 Traveller information

7.1 General overview

Dynamic message sign (DMS) is a generic name for various types of variable message signs (VMS) as described in these guidelines and may include freeway VMS used on the mainline, tactical VMS used on the mainline as part of a lane use management system, and arterial road or ramp control RC3 VMS used prior to ramps entering the freeway.

DMS messages inform road users about the current downstream traffic conditions on the freeway and may include information about travel-time, congestion, extent of delay, incidents, roadworks, special events and weather conditions.

7.2 Freeway variable message signs

Freeway variable message signs (VMS) are permanent VMS on the mainline that provide 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 such as delays, traffic incidents, roadworks, special events and the weather conditions (if applicable). This enables road users to make informed travel decisions and to choose the most efficient route to their destination. This can also help reduce congestion.

En-route traveller information helps traffic operators to optimise 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. They support the operation of LUMS, where relevant as shown in Figure 7-1 (left). The VMS default operation shows real-time travel-times and freeway traffic conditions to destinations / interchanges downstream or on intersecting routes as shown in Figure 7-1 (right).

Figure 7-1 Freeway mainline VMS: incident message (left) and travel-times on Kwinana Freeway mainline (right)

For off-route destinations prior to system interchanges, freeway-to-freeway VMS provide specific traffic condition information for road users leaving the freeway. For example, travel-times to destinations on the intersecting route (see Figure 7-2), or other relevant information for incidents, (see Section 7.4).

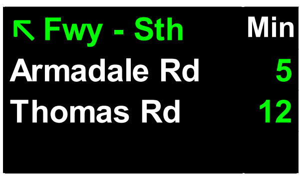

Figure 7-2 Mainline VMS RC3-C: Freeway mainline VMS: travel-time display for exit traffic conditions

Warrants

Mainline VMS including location, spacing, content and message hierarchy, shall be considered and designed in accordance with the Main Roads' Smart Freeways: Variable Message Signs Guidelines (2020), and the requirements for:

- freeways with foundation-level ITS (see Section 5.1)
- freeways with higher-order ITS (see Section 5.2), and
- freeways with LUMS, including ALR, to support the LUMS operation, such as lane closures and/or reduced speed limits.

Technology and installation configurations

As a general principle, VMS shall 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 shall have functionality to be able to display incident warnings as well as real-time traffic information and travel-time information.

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. See Section 8.3 for guidance on data for the arterial road network and Section 8.5 for guidance on travel-time algorithm.

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

7.3 Tactical VMS

Tactical VMS (TVMS) provide real-time warnings and instructions to road users as part of a Lane Use Management System.

TVMS are generally installed on the LUMS gantries as shown in Figure 7-3 and are used for messages to help road users understand the reasons for lane closures or lower speed limits.

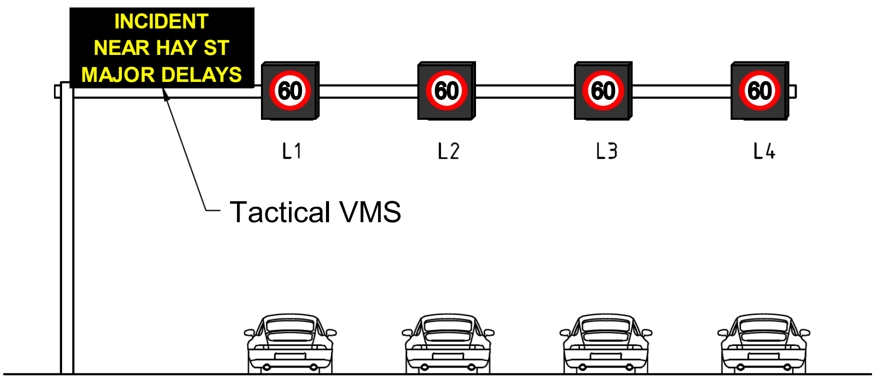

Figure 7-3 Tactical VMS used as part of a LUMS scheme

Warrants

Tactical VMS shall be considered within a Lane Use Management System and designed in accordance with the Main Roads' Smart Freeways: Variable Message Signs Guidelines (2020).

7.4 Freeway-to-freeway VMS

Freeway-to-freeway VMS (RC3-C) are used in advance of a freeway-to-freeway interchange to provide traveller information to exiting road users relating to the intersecting freeway or exit ramp. The freeway-to-freeway VMS is installed adjacent to the freeway mainline prior to the interchange and are essential to provide advance warning and information if there are ramp signals on the ramp where it enters the intersecting freeway.

The traveller information may include integrated messages relating to traffic conditions, and if not needed for ramp signals operations, travel time to key destinations on the intersecting freeway. The VMS is also capable of providing traveller information to help real-time traffic operations, e.g. during incidents, lane or ramp closures, congestion, roadworks, etc. Example messages are shown in Figure 7-4.

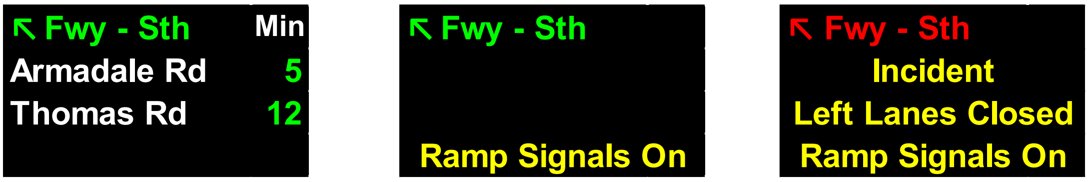

Figure 7-4 Examples of freeway-to-freeway VMS (RC3-C) displays (Roe Highway westbound traffic approaching Kwinana Freeway)

Warrants

Freeway-to-freeway VMS as part of general traveller information or ramp signals design shall be considered in the context of the following requirements:

- freeways with foundation-level ITS (see Section 5.1), and
- freeways with higher-order ITS (see Section 5.2).

Design requirements including location, sign size, spacing relative to other signs, content and messages shall be considered in accordance with the Main Roads' Smart Freeways: Variable Message Signs Guidelines (2020), and in the context of ramp signals design, the Main Roads' Supplement to Victoria's Managed Motorway Design Guide Volume 2: Part 3.

7.5 Arterial road VMS

Arterial road VMS (RC3) for ramp signals or general traveller information at entry ramps (see Figure 7-5) 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 and ramp traffic conditions, such as level of congestion, incidents, road works and closures, etc.

Arterial road VMS come in the following sizes to suit the roadway speed environment:

- RC3-A for lower speed arterial road environments, i.e. up to 60 km/h
- RC3-B for higher speed arterial road environments, i.e. up to 80 km/h, or locations remote from the freeway interchange

Arterial road VMS at strategic locations on the arterial road network are able to influence route choice and can assist in diverting traffic away from the freeway during congestion or an incident.

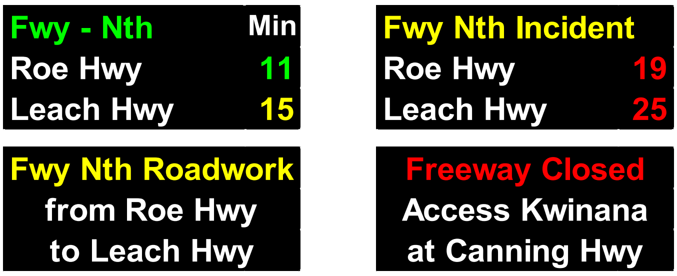

Figure 7-5: Examples of arterial road VMS displays

Warrants

Arterial road VMS as part of general traveller information or ramp signals design shall be considered in the context of the following requirements:

- freeways with foundation-level ITS (see Section 5.1), and
- freeways with higher-order ITS (see Section 5.2).

Design requirements including location, sign size, spacing relative to other signs, content and messages shall be considered in accordance with the Main Roads' Smart Freeways: Variable Message Signs Guidelines (2020), and the Main Roads' Supplement to Victoria's Managed Motorway Design Guide Volume 2: Part 3.

7.6 Public transport VMS

VMS can be used to display information about 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 may include:

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

Warrants

VMS that display real-time public transport information to assist with driver route / mode choice are not critical for Smart Freeway operations, however may be considered at locations where public transport is a feasible alternative, e.g. along the Kwinana Freeway or Mitchell Freeway where there are train services, including stations and parking.

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

Technology and installation configurations

To avoid confusion, public transport information shall be displayed on separate VMS, i.e. not on freeway VMS (Section 7.2) and arterial road VMS (Section 7.5), which display road and traffic information. The type of signs used to display the public transport information should be compatible with the freeway management system to provide consistency in the technology installed on the network.

7.7 Advance warning flashing signals/signs

Advance warning flashing signals may be used in various situations to attract attention to a specific, and generally significant hazard, which may be unexpected or of higher than normal potential risk that may use conventional warnings. 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/signs can be:

- single flashing display or, more conventionally, twin alternating displays that draw attention to a static sign, or as an integral part of a warning sign, or
- dynamic VMS with a flashing message (preferred).

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 for 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 structure). The fixed part of the sign has advice on appropriate corrective action (e.g. take the next exit).

Warrants

Deploy advance warning flashing signals in accordance with the relevant standard 67-08-1 (Main Roads 2012b).

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

- at steep descents
- at sharp curves
- at large speed drops
- Sites with limited visibility (i.e. where fog occurs on a regular basis)
- in advance of traffic signals at the end of freeways
- in advance of low clearance sites such as tunnels and bridges (with over-height detection), and
- over-height vehicle detection and warning systems on the principal freight network.

Technology and installation configurations

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

7.8 Pre-trip and in-vehicle traveller information

In addition to roadside signage, there are several pre-trip and in-vehicle measures that can be used 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

Main Roads uses various 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 Smart Freeway operations. However, existing services should be used 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-vehicle traveller information include:

- **Webcams** – fixed CCTV cameras used for the sole purpose of live streaming videos of the network on the Main Roads' website for public viewing; they are not used for traffic management purposes.
- **Vehicle sensors** – traffic data from vehicle sensors are used for graphical maps displaying real-time travel conditions such as average speeds and congestion on the network, accessed via the Main Roads' website. These maps can also display incident and event data, and help travellers in their route and mode choice decision.
- **Bluetooth** – the Addinsight data can provide valuable information relating to trip travel time, origin-destination or other studies.

Technology and installation configurations

The key consideration for Smart Freeway 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, e.g. the PTZ function is not required and lower resolution may be appropriate.

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

7.9 Fixed signage

Within a Smart Freeway environment, additional fixed signage can alert and educate drivers on the change in the operational conditions. These signs can provide general instructions or information, or 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

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

- gateway signs located upstream of the Smart Freeway treatments, including at entry ramps, to inform road users about special characteristics, e.g. no emergency lane, and
- signs located within the Smart Freeway treatments to reinforce safety critical information (e.g. distance to emergency stopping bay / safe stopping location when an emergency lane is not present).

Technology and installation configurations

Additional types of fixed signs may need to be considered alongside the standard requirements for fixed signage for 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-vehicle information.

The 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 public education programs, where applicable.

8 Network intelligence ITS

8.1 Vehicle detection systems

Vehicle sensors collect real-time traffic data as part of a vehicle detection station (VDS), including volume, speed, occupancy (density) and vehicle classifications lane-by-lane. The real-time data is the basis for monitoring and control of the freeway, e.g. vehicle sensor data is the primary input for CRS algorithms, operation of VSL signs, travel-time calculation algorithms and some automated incident detection systems.

The real-time data used for traveller information enables freeway conditions such as travel-times and traffic conditions to be displayed on VMS. It is also provided to third parties for incorporation in commercial applications such as satellite navigation systems.

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

Warrants

Vehicle sensors shall be installed on all freeways. Vehicle sensor locations and spacing shall be designed according to guidance in the Main Roads' Supplement and Victoria's MMDG Volume 2 Part 3, Chapter 5.

Varying requirements for installation apply to freeways requiring foundation level ITS (see Section 5.1) and freeways requiring higher-order ITS (see Section 5.2). Provide data for all traffic lanes. Vehicle sensors may need to extend beyond a project area for the purposes of operational control and/or data collection.

Technology and installation configurations

Vehicle sensors are manufactured to operate using a range of technologies including:

- Wireless magnetic field sensors.
- Loop-based sensors embedded in the road surface.
- The Infra-Red Traffic Logger (TIRTL) which is suitable for CRS traffic management control of the mainline as it is highly accurate and reliable. These are mounted on the roadside to be non-intrusive.
- Radar sensors or video-based systems unsuitable for CRS traffic management control of the mainline, but may be suitable for AID.

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

- Accuracy of data for the required uses, i.e. type and quality, particularly for a CRS system.
- Availability of data, i.e. reliability and repair.
- Whole-of-life costs, including traffic management for installation and repair.

8.2 Closed circuit television cameras (CCTV)

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 cameras are also essential for monitoring the ramp signal operations, including day-to-day monitoring of ramp queues, mainline merging, driver behaviour and identification of operational issues as well as fine-tuning of the algorithm. In the use of ALR operation, CCTV is crucial for surveillance of traffic lanes and emergency stopping bays. The cameras are also used to verify information displayed on VMS and LUMS.

CCTV cameras on the arterial road network can help to assess queue lengths and conditions on the approach roads to the freeway.

CCTV images are monitored by traffic operators in the Road Network Operations Centre (RNOC) and may also be shared with external stakeholders for incident and emergency management, e.g. the police and public transport operations.

Warrants

Full coverage

CCTV cameras shall be installed for full and unobstructed coverage of both carriageways of the freeway, i.e. 100 per cent coverage. The RNOC should be consulted about suitable locations, as well as consideration of physical restrictions, e.g. from site visits and/or design plans, that may obstruct visibility. Full coverage shall 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 1,000 m spacing on straight road sections, depending on height, technology and visibility, and
- closer spacing at curved alignments, underpasses and visibility restricted areas.

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

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

Overlapping coverage

Overlapping coverage, i.e. 100 per cent coverage, 100 per cent of the time, shall be provided at key bottlenecks where flow breakdown is a significant risk, complex segments of the freeway, sections with ALR, all emergency stopping bays, and at freeway-to-freeway interchanges. Overlapping areas of coverage shown in Figure 8-1, have 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.

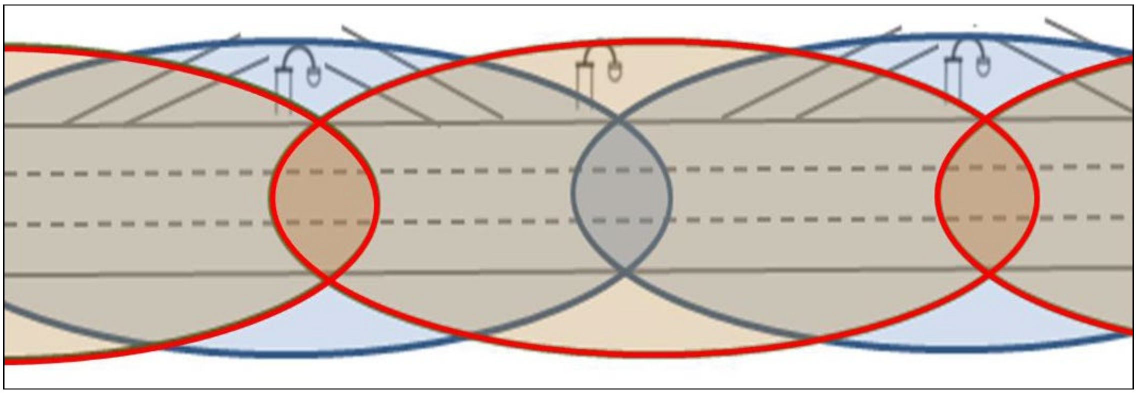

Figure 8-1 Full (blue) and overlapping (blue and red) coverage of CCTV cameras on a freeway

Technology and installation configurations

Pan-tilt-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 with sufficient rigidity to avoid excessive movement and shaking of images, e.g. gantries with pole extensions or ramp signal poles. Tilting poles shall be considered as they have maintenance benefits.

CCTV installed on freeway sections with a foundation level of ITS shall be located to facilitate cost-effective upgrade to enhanced levels of provision for Smart Freeways, i.e. 1,000 metre to 2,000 metre spacing on the mainline.

8.3 Arterial road traffic data (from SCATS)

Smart Freeway treatments should be implemented as part of a whole-of-network operations approach and to enhance overall journey-time information across the arterial and freeway road network. Arterial road traffic data may also be used for traveller information directed at freeway users, e.g. traffic conditions, travel-times and average travel speeds. Arterial road traffic data is acquired through vehicle sensors at traffic signals and mid-block signals, with additional intelligence provided to traffic operators via CCTV cameras and/or Bluetooth systems.

Warrants

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. In some cases, gaps in the provision of arterial traffic data may require installation of additional field equipment.

Technology and installation configurations

The installation of devices shall align with relevant requirements outlined in Section 6.2 (CRS), Section 8.1 (vehicle sensors) and Section 8.2 (CCTV).

8.4 Roadside help phones

Roadside help phones facilitate road user safety and security by providing a means of communication to Main Roads in the event of a breakdown, crash, or other incident when the driver requires assistance.

Roadside help phones also 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 roadside help phones are identified as priority calls through the Customer Information Centres (CIC). The CIC alerts relevant internal stakeholders, including traffic operators, as well as the emergency services and towing services as required.

Warrants

Roadside help phones shall be provided on all freeways in accordance with the Main Roads' Guideline for Emergency Stopping Bays and Roadside Help Phones.

Where operational strategies are implemented to enable dynamic full pavement use, i.e. ALR, roadside help phones shall only be provided in emergency stopping bays and not adjacent to the carriageway.

Technology and installation configurations

Reference shall be made to Main Roads' Guideline for Emergency Stopping Bays and Roadside Help Phones.

8.5 Travel-time algorithms

Travel-time algorithms support real-time travel time and traffic condition information. They also provide 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. Main Roads started displaying real-time travel times on freeway VMS in August 2017.

Warrants

Display real-time travel-time information using travel-time algorithms where capable VMS are available on freeways and arterial roads (Sections 7.1 and 7.4), subject to operational guidelines.

Technology and installation configurations

Travel-time calculations are determined from both VDS and Bluetooth data with processing of average travel speed for sections of known length by the freeway management system. Other technologies, e.g. ANPR, GPS, mobile phones and vehicle identification tags are also potential solutions.

The choice of key destinations for freeway travel-time calculations should be consistent with the Main Roads' Smart Freeways: Variable Message Signs Guidelines (2020). This source also has further guidance on the methodology for calculating travel-times from vehicle sensor data (Section 8.1) as well as consideration of possible future methodologies such as predictive travel-time.

8.6 Automated incident detection (AID) systems

AID systems enable direct and automated detection of incidents or irregular traffic flows. They can be used to alert operators of possible incidents through detection of slow-moving, stationary or wrong way vehicles, unauthorised pedestrian, 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.

With operator confirmation of an incident detected by the AID system, control interventions can be initiated, particularly LUMS operator endorsed automated traffic management and VMS messaging in response to the occurrence of incidents and changing network conditions. A CRS response to an incident may also be available.

Warrants

AID may be considered to improve road safety, incident detection and response times. Any freeway with higher-order ITS will benefit, but particularly at the following freeway locations:

- complex segments of the freeway and particularly sections with ALR
- freeway-to-freeway interchanges
- key bottleneck areas where flow breakdown is a risk
- sections with a higher exposure and risk of incidents, e.g. heavy traffic flows throughout the day
- sections where there is no, or reduced width, of the emergency lane, e.g. tunnels, bridges
- emergency stopping bays within sections of freeway with ALR

Technology and installation configurations

AID systems can use a range of technologies, including:

- video image processing with motion detection technologies based on fixed-CCTV cameras and artificial intelligence
- vehicle sensor algorithms using traffic speed, flow and direction data, and
- radar vehicle sensors with data processing algorithms (this is the system implemented in the Smart Freeways – Kwinana Freeway Northbound Project).

Historically, AID systems have had limited success, and in some cases, the high frequency of false alarms has meant systems are then turned off. Therefore, systems being considered for use or trial, particularly where additional infrastructure costs are required, (i.e. not just software using existing vehicle sensors), shall have documented performance outcomes, preferably by an independent evaluation, rather than manufacturers undertakings.

Important performance characteristics for an AID system include:

- detecting stopped vehicles
- detecting differences between a crash or other incident, compared to slow moving traffic or congestion
- automatically raising an alarm to alert the control room operators
- minimising false alarms, and
- functionality to automatically bring up images if the incident location on screen in control room from the nearest CCTV camera. This can help an operator's verification process.

The system shall generally cover all lanes, including the emergency lane and emergency stopping bays on sections of freeway with all lane running.

The technology should be effective for both day-time and night-time operations. For some systems, CCTV cameras and vehicle sensors used for surveillance, monitoring and traffic data provision may be suitable for AID. However, at some locations, additional field equipment might be required to suit the requirements of the system, e.g. radar-based systems.

8.7 Communications and data sharing with stakeholders

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

- external stakeholders, e.g. WAPOL, the Public Transport Authority (PTA), media and the public
- internal stakeholders, e.g. Customer Information Centre and on-road teams of officers and incident response vehicles that patrol the network for surveillance purposes, provide rapid on-scene response during incidents or to conduct maintenance activities, and
- internal officers working in the RNOC situation room for a major incident.

Video sharing also takes place between Main Roads and other stakeholders including WAPOL and PTA under the state CCTV strategy. The video wall in RNOC has been configured to enable display of images from both Main Roads' and PTA CCTV cameras.

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.

8.8 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, such as via VMS and/or VSL. For example, displaying reduced speed limits during heavy rainfall or high wind speeds to improve safety.

Warrants

Given the breadth of applications, there is limited general guidance for environmental monitoring and warning systems. Environmental monitoring and warning systems shall be considered on the basis of risks and consequences.

Environmental monitoring systems may need to be considered at certain locations to provide warning to road users about specific adverse weather conditions that commonly affect travel on that part of the network.

Network intelligence interventions such as vehicle sensors 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 VSL signs.

Main Roads uses a fog warning system on a section of Kwinana Freeway near Thomas Road and flood-monitoring sensors on Leach Highway near the Perth airport.

If new systems are being considered, they shall be compatible with current Main Roads' control and monitoring systems.

9 Foundation ITS infrastructure

9.1 Communication network

Communications for transmission of real-time data between field devices and the central control system underpin ITS. It enables the transfer of data and provides the ability to monitor and control these devices remotely. As further Smart Freeway upgrades are carried out, the communications network may also need upgrading to ensure that the system can operate effectively to meet system requirements.

With increasing density of ITS assets in freeway corridors, having high-quality communications, such as fibre optic cable available within the freeway corridor is essential. High-capacity communications infrastructure is also a key enabler for future vehicle to infrastructure communication.

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

- **Capacity (i.e. bandwidth)**, to accommodate additional ITS assets including planned projects and future upgrades.
- **Resilience (including reliability redundancy)**, to ensure there is no single point of failure in communications between field equipment and the RNOC.
- **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. A real-time monitoring and automated alarm system for all switches of electrical infrastructure across the Traffic Control System Network (TCSN) is monitored 24/7.

Development of the communications network shall also consider future requirements.

9.2 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 as well as the option of individual connections.

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 RNOC to prevent equipment failure, which may have road safety implications. Separate guidance relating to uninterrupted power supply (UPS) is provided in Main Roads' Specification 713.
- **Monitoring and fault management**, to ensure there are appropriate systems in place to minimise the occurrence and impact of power faults (also see Section 9.1).

9.3 Road Network Operations Centre (RNOC)

RNOC at 2 Victoria Avenue, Perth has enabled the Main Roads' Network Operations Directorate (NOD) to co-locate and merge their operational functions from the Don Aitken Centre (DAC) and the Traffic Operations Centre (TOC) into an integrated, fit-for-purpose, technologically advanced and real-time environment to operate Smart Freeways and future tunnel infrastructure. The TOC at 18 Newcastle Street, Northbridge continues to provide real-time operations for the Graham Farmer Freeway tunnel and is maintained as a fall-back control room.

The RNOC has provided improved management of the road network through pervasive situational awareness and a common operating picture to ensure the safe and efficient movement of traffic under a framework that empowers Network Operations to make rapid, effective and data-supported decisions in a real time environment.

The RNOC control room provides the required resources and technological capabilities to provide ongoing management and operation, to optimise the current and future road network including Smart Freeways.

The real-time traffic operation (RTTO) team occupying the RNOC control room is responsible for providing 24/7 real-time traffic incident management and planned events management within Perth's metropolitan road network. The RNOC control room's primary functions and responsibilities include:

- monitoring and managing real-time operation of state road network in Perth metropolitan area to minimise impacts of congestion, incidents, roadworks and planned events
- providing traffic operations planning expertise for planned events
- sharing up-to-date road and traffic condition information, via public affairs coordinators, to the public and media using multiple platforms, and
- liaising with Main Roads' operational partners including the Police and emergency services, Public Transport Authority, local government and other traffic management organisations.

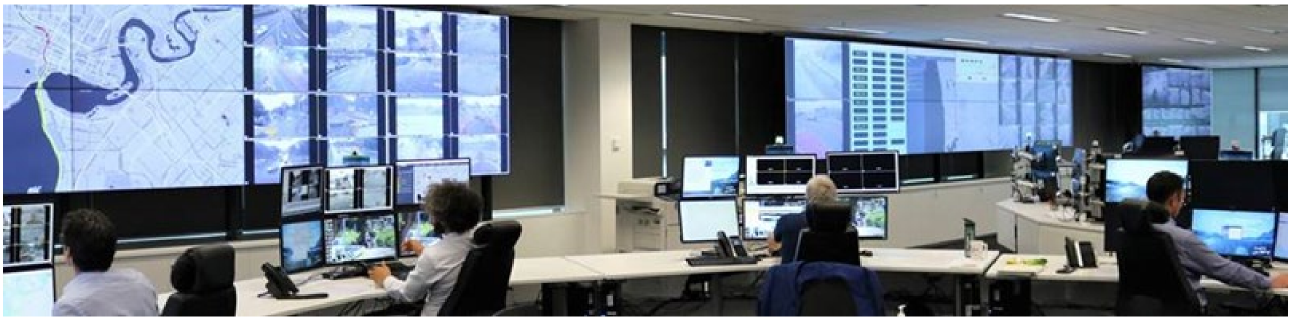

Figure 9-1: The RNOC Control Room

9.4 Smart freeways control system

Main Roads' ITS equipment deployed in Smart Freeways is currently managed by a single control system (STREAMS provided by TRANSMAX). This system has a single operator interface for the various sub-systems and field equipment that deliver Smart Freeway functions.

Ideally, the same control system should be used for all network operations activities and ITS technologies deployed on the Main Roads' network, including freeways, arterial and regional networks. This provides the integration required for efficient, effective management of traffic across the network.

STREAMS is an integrated software platform with an open and service orientated architecture. This also has flexibility for future software and technology developments.

9.5 Freeway performance evaluation

Freeway performance shall be measured for operational performance analysis and optimisation, monitoring and reporting. Historical traffic and other network data is archived and accessible to relevant stakeholders. Traffic data can be acquired from vehicle sensors as well as by other devices, including Bluetooth and third party sourced GPS-based systems. Smart Freeway design should consider requirements for project performance evaluation as well as ongoing network performance evaluation.

The Smart Freeway system operators, particularly for CRS, need to carry out regular analysis and evaluation of traffic data for fine-tuning and improving freeway performance. Specialist skills are required for these activities.

9.6 System performance management

All aspects of a Smart Freeway should operate in a manner that ensures high reliability, (i.e. 99.99 per cent 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 RNOC should be designed to minimise faults occurring and have automated fault detection and reporting / alarms that minimise fault detection resolution times.

Maintenance contracts shall ensure that faults critical to the safety or performance of the network, such as LUMS (safety critical) and CRS / vehicle sensors (critical for safety and productivity) are repaired within required response times.

9.7 Other considerations

The following sub-sections provide further guidance on other considerations for deploying ITS and technology interventions as part of Smart Freeway treatments.

9.7.1 Incident response teams

The incident response service (IRS) consisting of officers and vehicles patrol the network for surveillance purposes and 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 Smart Freeway operations on sections where there is ALR, i.e. no emergency lane, or for critical sections of the network, including those with limited capacity relative to traffic demand. The level of resources required for peak and off-peak times needs to be considered. This depends on service delivery standards, expected incident rates, number and location of vulnerable sections of the network and type of Smart Freeway treatments installed.

9.7.2 Lighting

There may be specific Smart Freeway treatments where lighting is required to improve road user safety and security, or to assist with network surveillance. This should be considered in the context of the Main Roads' street lighting policies and guidelines.

9.7.3 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) used for reporting against national performance indicators and other purposes.

Smart Freeways design shall consider all ITS applications to ensure that the required foundation infrastructure is sufficient to facilitate system and technology integration where appropriate.

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