

Managed Motorways Framework

Network Optimisation & Operations Rationale and Technical Requirements

March 2017

VicRoads Managed Motorways Framework



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Section 1

Summary - Introduction

This Framework provides the rationale and supporting evidence behind the active management of Victoria's motorway (also referred to as freeway) network that seeks to maximise performance from this expensive asset for the benefit of individual road users and the broader community.

The Victorian active management approach is:

- Outcomes-driven, with operational success measured by network performance outcomes;
- Focussed on improving operational connectivity between motorway routes and the arterial road network, as well as between multiple road operators, including on-road public transport operators, to maximise productive use of the asset at all times;
- Based on the understanding that technology is an enabler, but it is the operation and optimisation of technologies that creates the benefits; and
- Moving towards an ultimate goal of multi-modal network optimisation and journey management.
- Adopting a safe system approach as per VicRoads' Road Safety Step Up Strategy to the design and management of motorways to reduce the incidence and severity of crashes

The overarching purpose of the Framework is to clearly demonstrate the link between the benefits of active management on the motorway network and the critical operational and system performance requirements for the enabling technologies that need to be met to ensure those benefits are realised.

This introduction provides an overview of the content of the Framework, as well as background to the Systems Engineering process that has driven its development, with focus on roles and responsibilities of the key players in implementation of the active management approach.

This Framework builds on various other VicRoads policy and guideline documents, which should be read in conjunction with this Framework.



1. Introduction

The active management of Melbourne’s motorway network is an important road network optimisation and operations initiative to get better performance from this expensive community asset, benefiting individual road users and the broader community.

An effective active management approach is outcomes-driven. This Framework provides a clear path from the desired benefits for road users and the community to what this means for how motorways should be managed, and what level of system performance is required to meet operational needs and user expectations. This will ensure that once infrastructure is installed on the road, the ongoing operation and maintenance of the system continues to achieve the optimal outcomes for our customers. **The ultimate measure of success is the performance of the road network, not the system.**

As more of Melbourne’s motorway network is actively managed, there is opportunity for **improved operational connectivity between routes and intersecting arterials to maximise productive use of the motorway asset at all times** and deliver further benefits to road users. This requires common understanding of the underlying principles and requirements for operation of each of the active management tools as well as how they work cooperatively in support of the same outcomes. This Framework recognises the increasing layers of active management from basic traffic management interventions and optimisation of linear routes towards a fully connected motorway and arterial road network.

The active management of motorways depends on the use of technology to perform optimisation activities, to assist interventions (operational responses), to inform travellers and to gather the network intelligence needed to enable these functions. **This technology enables the performance of the network optimisation and operations functions, but it is the optimisation and operations that create the benefits.**

This Framework summarises how VicRoads uses active management to optimise and operate its motorway network as well as some ways it will seek to further improve this active management into the future. **The Framework includes the rationale and supporting evidence for this network optimisation and operations approach and sets out requirements for the enabling technologies.**

The Safe System approach is completely embedded in how VicRoads manages its motorway network, it recognises that people make mistakes and that this can lead to crashes, which requires the design, construction, maintenance and operation occurs in a manner to ensure that the incidence and severity of crashes are reduced.

In line with the systems engineering approach, this Framework will provide a critical set of technical requirements as part of the total technical requirements required for Managed Motorways. **The requirements in this Framework are critical requirements, as they directly relate to the way in which the network optimisation and operations create benefits for road users and the wider community.**

The Framework draws heavily upon existing VicRoads’ publications, including the Managed Freeway Policy (September 2013a), Managed Freeway Guidelines (August 2014) and associated design and operational guidance material for ramp signals, integrated speed and lane use management and traveller information. In some cases the Framework extends beyond these existing publications, building upon lessons from Managed Motorways implementations in Victoria, interstate and overseas, as well as VicRoads’ assessments of the changing needs for the future.

1.1 Document structure

This Framework is structured to address a series of key questions relevant to the active management of Melbourne’s motorway network.

Table 1.1 Document structure

Key questions	Section	Section Title
Why should we actively manage our motorway network and to what end?	2	Why invest in active management?
How can we actively manage our motorway network?	3	Levels of active management
	4	The Managed Motorways toolkit
What does this look like for a system operator and a road user?	5	Human Machine Interfaces (HMIs)
How do we specify these tools to ensure they do the job?	6	System performance criteria
What critical requirements should be included in procurement contracts?	7	Performance requirements for Managed Motorways tools
How do we sustain and strengthen the benefits, and what are future considerations for motorway operations?	8	Next steps

The appendices contain further information regarding Managed Motorways case studies and benefits (Appendix A), the current and future proposed LUMS system architecture (Appendix B) and the list of proposed future development of Managed Motorways tools (Appendix C).

Note that motorway and freeway are used interchangeably throughout this document.

1.2 The Victorian approach to Managed Motorways

The definition of a “Managed Motorway” internationally and across Australia varies significantly and includes many different concepts. For example, any motorway having one or more ITS tools operating (e.g. VMS and VSL) may use the term Managed Motorway. If basic ramp metering or lane control systems are used, it may also be considered to be a managed motorway; hence there can be considerable confusion about what constitutes an effective managed motorway. This approach was adopted in the City of Melbourne

In 2002 a key reason VicRoads moved to a unique Managed Motorway regime was the realisation that we could “no longer afford to build roads to always meet peak localised demands or overall peak network demands”. Therefore, urban motorways as a network needed their demands to be managed to deliver the overall best outcome for the city of Melbourne in terms of equity, safety, efficiency, reliability and productivity (being the product of speed and flow).

The motorway network also needed to be designed and operated to be resilient and work well when put under stress including during excess demands, incidents and maintenance events. A resilient system will respond to and quickly recover from a major shock. Therefore, VicRoads’ approach to both the strategic planning of the motorway network and it’s operation is to provide flexibility for traffic management and diversions and rapid system response to manage and mitigate disruptive events. This approach ensures motorway conditions return to those that are most conducive to support the State’s economy and liveability, optimising transport outcomes every minute of every day, every day of the year.

The VicRoads approach to Managed Motorways is unique on an international scale and has come to be known by many overseas (for example in the USA) as the ‘Melbourne Approach’. Its application varies significantly from that in other jurisdictions in Australia particularly at the detailed and technical levels of implementation. Whilst high level descriptions of the adopted ITS tools and methodology may sound similar to other applications, the ‘Melbourne Approach’ is differentiated by the holistic approach focusing equally on 12 different elements that combine together to give the overall motorway productivity outcome as follows:

- 1 detailed understanding and application of physics and dynamics of traffic flow and behavioural science to operate motorways as a system where they regularly operate under stress.
- 2 physical design (geometric) of the motorway to ensure safe operation and to minimise turbulence in the traffic flow on the mainline and ensure the entry and exit ramps are designed to store and regulate dynamic traffic demands into and out off the motorway network¹.
- 3 operational design to ensure the motorway can be actively managed in real time and can be controlled during non recurrent and incident events, supported by the provision of lane control, speed control and messaging to support safe and efficient operations¹.
- 4 real time feedback control through adoption of high quality control algorithms and ITS tools that operate at the lane, link, route and network levels. These algorithms and tools enable the control system to activate and adapt in a targeted manner to the many instantaneous traffic flow problems that arise in a motorway network when traffic conditions put it under stress².
- 5 a consistently applied organisation operational policy (written and/or practiced) that understands that the best overall outcome for the entire road network requires motorways networks to be managed as a complete system at all times to sustain high productivity and safety outcomes³.
- 6 high quality ITS devices deployed in the roadway (incl. detection, telecommunication, power and control systems) with a strong focus on high accuracy and rapid delivery of real time data.
- 7 the quality and timeliness of the day to day (24/7) maintenance service for all ITS devices ensuring high availability of ITS tools to enable their full functional capabilities.
- 8 the quality and functionality of the ITS tools (e.g. backend system and user interface) deployed in the Traffic Management Centre (TMC) and network optimisation teams.
- 9 the focus on real-time operation of the road, including training of staff.
- 10 the focus on regular historical analysis of motorway performance;
- 11 the focus on regular tuning the system parameters by specialist optimisation teams with the aim of seeking improved performance understanding, to enable continuous improvement⁴.
- 12 the production and maintenance of high quality practice oriented design guides for use by practitioners (with regular reviews of guides to incorporate new and emerging learnings).

¹The civil infrastructure (mainline, ramps and arterial road interfaces) are designed so that motorways can be operated in real time to maximise road safety, reliability and vehicle throughput as well as minimise travel time and unnecessary turbulence between vehicle movements. The civil motorway infrastructure needs an iterative design process to balance the design volumes to mainline lane and ramp arrangements and the operational design to ensure that traffic efficiency, safety and incident response and event management can be achieved. This takes account of randomness and dynamic issues such as demands, road user behaviours, varying vehicle mix and varying origin destination patterns and other conditions experienced on motorways at the sub 1 min level. This ensures 24/7 higher productivity for the motorway and the broader road network and optimised flow outcomes during periods of high demand.

The design must be appropriate to accommodate the various traffic patterns and demands that occur over the entire day. (This provides the basis for good 24/7 operations to meet the community needs and transport demands, even when control systems do not need to intervene.) Unfortunately forecast design volumes used for the planning of projects typically only consider two traffic generalised patterns comprising trips patterns and demands that cover the AM and PM peak periods. In reality traffic patterns and demands vary significantly during the peak periods and are never the same on any two days of the year; hence the need for ITS tools to complement design and smooth disturbances and variability of demands across the network in real time. It can also be implied that if deployment of ITS tools and devices is undertaken without the complementary infrastructure, system design, maintenance, operational expertise and supportive policy regime, then the ITS benefits (safety and operational) will not be realised and managed motorway benefits should not be claimed in any business case.

²Likewise ITS tools should not be considered to be an alternative or cost saving measure to replace appropriate motorway design standards but rather only to complement good motorway design practice and to appropriately intervene to smooth and balance demands across the network in real time to maximise mainline productivity, prevent flow breakdown and also achieve real-time flow recovery after traffic flow has broken down. Hence a motorway can only achieve its highest productivity if both appropriate design and appropriate operational practices are implemented.

³The design capacity of a managed motorway's operation is determined by its weakest link (refer US 'HCM 2010' and 'German HBS') – therefore any uncontrolled entry no matter how small (i.e. <100 veh/h) results in that section of road being deemed to be unmanaged. If the operational policy (documented and/or practiced) allows any excess ramp queues to be simply released (common terminology: flushed or dumped) into the motorway under normal operations, the motorway is not considered to be managed – hence a 15% reduction needs to be applied to any capacity or recommended design volumes for traffic modelling or economic analysis and this must apply to all sections downstream of the uncontrolled entry or the ramp where the release occurs. Refer: VicRoads Motorway Capacity Guide – Part 1: Metropolitan Managed Motorways.

VicRoads recognises that the best overall outcome for the entire road network, working as a single system, is when its high value, high capacity assets are optimised as this generally leads to the best overall system productivity. Also it is now known that while motorways are generally much safer than arterial roads when measured over the day or the year, the evidence clearly shows that when motorways are placed under stress and allowed (by action or inaction) to become congested casualty crashes (total numbers) rise significantly (4 -6 times higher) and the crashes change from single vehicle to multi-vehicles crash types. Therefore, at times of congestion or when the freeway network is operating near capacity, the best system outcome in terms of productivity and safety requires ramp control actions that prevent the collapse of motorway flows. Having operators regularly override control settings inhibits the real time automated control actions which prevent recovery from flow breakdown. Shifting localised problems on to the surface road on to the freeway network will generally not provide best overall system benefit for the community and generally results in suboptimal operation of both the motorway and surface road.

⁴Understanding and application of contemporary traffic and behavioural science in operating the FMS system acknowledges that bottlenecks by their very nature are inevitable in any motorway and can occur at any location at small time intervals i.e. 1min. Within a minute the freeway can move from level of service D to F as a result a disturbance of a single perturbation in a lane flow cause by e.g the interaction between 2 vehicles changing lanes or too many vehicles too close together at a single point in time in the same lane. Hence, day to day operations need to effectively match traffic demands in real time to the motorway network's dynamic capacity (every 20 seconds). This can be achieved by employing a control system that utilises accurate / reliable data, adjusts to constantly changing traffic demands, trip patterns, vehicle mix and varying driver capabilities and can be activated in such a manner as to prevent and recover from flow breakdown. Due to the variations and interaction of the many dynamic stimuli on the motorway network over time, it is essential that a specialist team with a good understanding of contemporary traffic control theory is able to oversee fine tuning of the control system.

A motorway can be designed and built within a few years but it must provide efficient and safe operation for decades to come. The right combination of design and ITS tool deployment and operational regimes (maintenance and tuning) will enable road agencies to the lock in the claimed benefits of significant motorway upgrades.

1.3 The Safe System Approach

The safe system approach is embedded into the entirety of VicRoads' method of active management of motorways and encompasses the design, maintenance and operation of these critical assets. It is an approach to road safety which recognises that humans, as road users are fallible and will continue to make mistakes, and that the community should not penalise people with death or serious injury when they do make mistakes. In a safe system, therefore, roads (and vehicles) should be designed to reduce the incidence and severity of crashes when they inevitably occur.

The safe system approach requires, in part (Australian Transport Council 2006):

- Designing, constructing and maintaining a road system (roads, vehicles and operating requirements) so that forces on the human body generated in crashes are generally less than those resulting in fatal or debilitating injury.
- Improving roads and roadsides to reduce the risk of crashes and minimise harm: measures for higher speeds roads including dividing traffic, designing 'forgiving' roadsides and providing clear driver guidance. In areas with large numbers of vulnerable road users or substantial collision risk, speed management supplemented by road and roadside treatments is a key strategy for limiting crashes.
- Managing speeds, taking into account the risks on different parts of the road system.

Road designers should be aware of, and through the design process, actively support the philosophy and road safety objectives covered in the Guide to Road Safety - Part 3 (Austroads 2008b).

1.4 Following a Systems Engineering process

Systems Engineering is an interdisciplinary field of engineering that focuses on how to design and manage a complex engineering system over its life cycle and is particularly useful for managing risk in technology-based systems. Some of the key features of systems engineering are in ensuring clearly documented requirements prior to systems design and the linkage of system testing and acceptance to those requirements and designs.

The US Federal Highway Administration (FHWA) began advocating the use of Systems Engineering processes to reduce the (otherwise substantial) frequency of ITS projects either failing to achieve completion or failing to realise benefits. The FHWA now requires the use of Systems Engineering analysis in all ITS initiatives funded by the US Federal Government.

In keeping with the multi-disciplinary nature of Systems Engineering, there are a number of organisational functions involved in the Systems Engineering process for Managed Motorways (refer to Table 1.2). These three organisational functional areas all have different perspectives and capabilities and a strength of the Systems Engineering approach is the structured process to draw these three areas together and provide a clear roadmap from objectives to outcomes (refer to Figure 1.1). In addition to managing project risk, the use of this Systems Engineering approach also improves benefit realisation and the return on investment.

The V-diagram in Figure 1.1 has been adapted to reflect the particular situation of Victorian Managed Motorways and shows how the purpose of active management is to achieve network operational outcomes (green) through traffic optimisation and optimisation methods (blue) that are reliant on technology (yellow). Some boxes are shaded in two colours, showing that although each step can only be led by one responsible party, at the interface between the organisational areas collaboration is required.

Although this Framework will not comment on each stage of the Systems Engineering process, it is worth making special mention of the Concept of Operations (ConOps). The simplest meaning of a ConOps is a document describing the characteristics of a proposed system from the viewpoint of an individual who will use that system. The preparation of a ConOps document normally includes a strong focus on scenarios as a means of engaging with the operational stakeholders to capture how the system will function from their perspective. This use of scenarios makes the ConOps process most useful for some levels of active management (see Section 3), particularly traffic management and control interventions but less well suited to outlining needs for optimisation activities such as route and network optimisation. This Framework should therefore be seen as complementing the ConOps process, as it covers the full suite of active management approaches for motorways. This Framework has considered VicRoads' current operational approach to active management, but is not intended as a substitute for a ConOps, which may add further requirements for active management beyond those found in this Framework.

Table 1.2 Organisational functions and roles in the Systems Engineering process

Organisational function	Roles in the Systems Engineering process
Network strategy	<ul style="list-style-type: none"> ● Establish network operational objectives and strategies ● Assess what this initiative needs to achieve ● Update the policy and regulatory environment ● Evaluate what difference this initiative made to the performance of the transport network ● Update network operational objectives, strategies and performance targets
Traffic requirements and operations	<ul style="list-style-type: none"> ● Establish the specific operational requirements for this initiative ● Establish the operational policy and rules for this initiative ● Establish the operational tactics and settings for this initiative ● Validate that the enabling technology provides the required functionality ● Operate the resulting traffic management tools, including interventions (responses) and tuning of optimisation tools ● Improve the traffic management tools and operational methods
Enabling technology delivery and operation	<ul style="list-style-type: none"> ● Establish the consolidated technology requirements to provide the operational environment ● Update the system architecture to meet any updated needs identified ● Design, implement and commission the enabling technology ● Accept the enabling technology into production ● Maintain the enabling technology ● Update the enabling technology for this and future initiatives

1.5 Understanding functional description of roads

This Framework principally targets motorways; however, it has been developed with the understanding that motorways are an integral part of the whole road network and the integration of the motorway operations within the road network needs to be holistic, recognising that trips on motorways form only a section of a journey across the road network.

The use of the term motorway within this document generally refers to road sections that operate as “uninterrupted flow” facilities. I.e. Traffic flow is not controlled by conflicting streams at intersections. The term “Surface Roads” is also utilised to describe the various non-motorway road types across the broader road network which connect to the motorway network. Whilst the use of the term arterial road may seem appropriate; the term “Surface Roads” is used to prevent confusion with the statutory classification associated with declared arterial roads. In the Framework, the functional use / classification of the road is important rather than the statutory classification.

It is acknowledged that across the motorway network, there is a broad spectrum of connections to the surface road network. In most cases, these connections are from statutory declared arterial roads; however, there are also a number of locations where entry and exit ramps connect to local roads, managed by other road operators, including municipal councils. The principles, tools and operations discussed within the framework equally apply to these lower order roads as in such locations they provide the mobility traffic function of access to the motorway. Motorway accesses associated with roadside service centres and facilities also need to be included as flows associated with such land use could cause flow disruption under certain conditions.

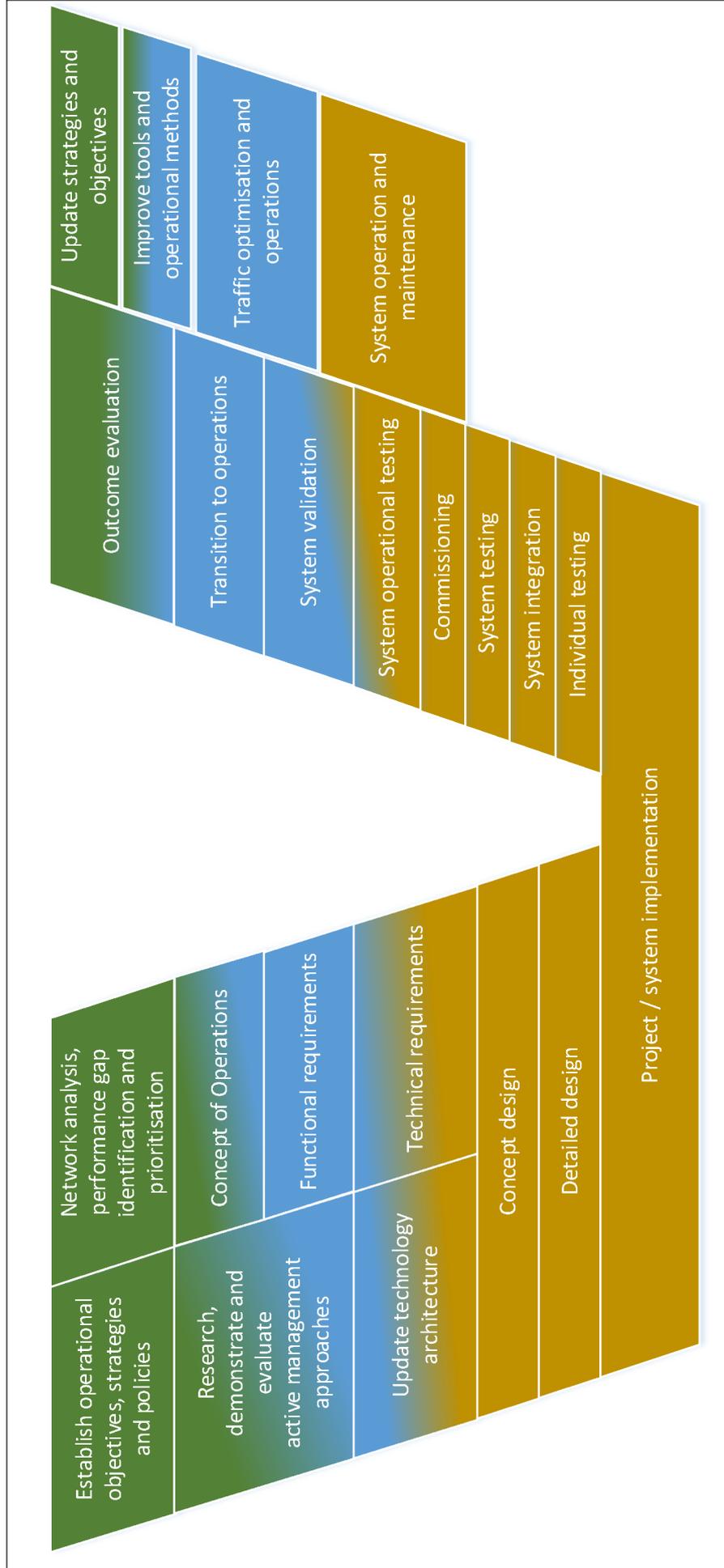


Figure 1.1 Systems Engineering process for Managed Motorways at VicRoads

Section 2

Summary - Why invest in active management?

Active management on Victoria's urban motorways supports a number of government and community objectives:

- Achieving maximum productivity in terms of the movement of people and goods from motorway assets, whose priority is to service general traffic, freight and sometimes on-road public transport demands;
- Improved journey outcomes for road users, for example in terms of travel safety, efficiency, reliability and through more informed travel choices; and
- Preventing the occurrence of flow breakdown and congestion on motorways that have detrimental effects on the wider arterial and local road network.

Managed Motorways are a proven approach with demonstrated benefits in Victoria and internationally. While the tools applied to a particular section of motorway may vary, the outcomes for road users are similar and are primarily seen in relation to improved throughput, capacity and travel speeds, more reliable travel times and safer traffic flows. There are also potential benefits for the environment and in relation to vehicle operating costs.

In Victoria, detailed analysis of the M1 Upgrade project has helped to demonstrate the benefits of the ITS services beyond the improvements to capacity provided through civil upgrade works. By looking at the improvement in average route throughput per lane instead of per carriageway, it can be seen that ITS has delivered an additional 16 to 19% improvement.

This section of the Framework provides more detail behind the value of freeways in Victoria to road users and the community and how they deliver benefits.



2. Why invest in active management?

To understand the investment rationale for active management, we must consider three perspectives:

- The role of freeways in the urban transport system (Section 2.1);
- What most matters to individual road users (Section 2.2); and
- How the broader community also benefits (Section 2.3).

We must also have a clear understanding of the benefits that can be realised through active management initiatives. Section 2.4 investigates the proven results of Managed Motorways in Victoria and other jurisdictions.

2.1 The role of freeways in the urban transport system

The role of freeways (also referred to as motorways) in Melbourne and major urban cities has often been simplistically analysed and because of their high profile and more obvious congestion problems, many opinions and policies have focused solely on their commuting role which in Melbourne comprises around 23% of daily trips (ABS Survey of Motor Vehicle Use, 2012).

Just one part of Melbourne's freeway network, the Monash-West Gate-Princes Freeway route (M1) services more than 1 million person movements each day. This means that the M1 carries more person movements each day than the entire metropolitan train service (Public Transport Victoria 2011-12 figures) and reflects the different functions served by different modes: fixed public transport systems tend to have narrow peaks with very high demand focussed on serving movements to/from common locations such as the central city, whereas urban freeway networks have wide peaks with high demand over the entire day that reflect a more distributed task.

The data in Table 2.1 is from the Cockburn area of Perth, at a location where a heavily used railway parallels a freeway for an extended distance. The railway is a double-track (one per direction) railway with a mix of express and all-stations services and the freeway has two lanes in each direction at that location.

Table 2.1 Different movement patterns on urban freeway and rail

	Railway	Freeway
Peak one hour person movements (7-8am)	8,740	4,200
Daily person movements	23,320	57,050
Peak one hour as a percentage of daily	37%	7%
Proportion of trips accessing inner city (not just CBD) - peak	85%	43%
Proportion of trips accessing inner city (not just CBD) – all day	84%	36%

There are some differences between Melbourne and Perth evident in this data. In Melbourne, we would expect a less strongly peaked demand for the railway due to more even demands over the day and a lower proportion of the freeway movements to be headed for the inner city, due a greater spread of destinations. Nevertheless we can see that:

- The railway better caters for peak demands of journeys heading to concentrated locations such as city centres and carries roughly twice as many people during the peak as the freeway;
- The freeway better caters for demands of journeys dispersed throughout the urban area and over the day carries more than twice as many people as the railway; and
- The two transport facilities (freeways and railways) complement each other by serving different functions and are not substitutes.

2.1.1 Business and service industry transport demand

The discussion in this section builds upon Austroads' Roads in the Community Report Part 1 (1997).

There has been a rapid increase in the service industry component of the Australian economy and it is estimated that employment in this sector now comprises 75% of total employment (Reserve Bank of Australia, 2012). Transport is an important component of these service industries, as it is often twice the percentage of total business costs in these industries compared to manufacturing industries.

Examples of service-based industries that involve travel on the network include tourism, sale persons, couriers, spare parts delivery, education, trades, construction materials, shopping and home based services such as cleaning and maintenance. Royal District Nursing Services, for example provides numerous daily services to homes rather than these services being delivered more expensively in hospitals and this involves significant road base travel. These industries are reliant on road transport for cross city travel and travel between municipalities to areas that may not be serviced by other transport modes.

As we add more and more of these service-based activities to our economy, a large percentage of the road trips they generate will tend towards having only a single person in the vehicle. Even during the morning peak period much of the travel is not commuting as a significant proportion of the drivers are already at work, such as truck drivers, couriers, tradespeople, salespersons, taxis and other service industries. Freeways have a lower apparent rate of passengers per vehicle compared to other road types (1.2 people per vehicle compared to 1.45 average), which appears to reflect the greater use of freeways for purposes that generally require only a single person to be in a vehicle.

2.1.2 SmartRoads, land use and the function of freeways

VicRoads' SmartRoads approach provides a framework for operation of the road network that considers both the different needs of different types of road user and the interaction between transport and land use. SmartRoads includes Preferred Traffic Routes that serve the strategic movement of general traffic (i.e. for all trip purposes, not just commuters/journey to work) along routes that have less conflict with other modes (e.g. on-road public transport, pedestrians and cyclists) or land use such as strip shopping centres. All freeways are designated as Preferred Traffic Routes and form the major sub-network of routes within Melbourne able to support the movement of traffic away from other conflicts.

In addition to their designation as Preferred Traffic Routes, freeways are on the Principal Freight Network in recognition of the critical role they play in accommodating road-based freight movement within Melbourne. Where applicable, freeways are also designated as Bus Priority Routes, such as on the Eastern Freeway.

The SmartRoads approach, as outlined in the VicRoads' SmartRoads Guidelines (2013b), recognises both the role of freeways in accommodating the movement of people and goods away from incompatible land and road uses as well as the importance for freeways to provide linkages to logistics and commercial centres. Both of these functions are important for the Melbourne of tomorrow as well as the Melbourne of today, as the shape of transport networks helps attract development and growth. The opening of the M80 Western Ring Road in the 1990s provides an illustration of how a freeway can contribute to industrial and logistics development.

Figure 2.1 illustrates how traffic in Melbourne is already relying on freeways as Preferred Traffic Routes as the arterial road network increasingly needs to serve priorities other than the movement of general traffic. Since 2007/8, almost all traffic growth on Melbourne's road network has occurred on freeways (light green columns) with traffic levels often slightly reducing on arterial roads (dark green columns). This trend is likely to continue with the densification of land use continuing to increase the demands on arterial roads for functions other than the movement of general traffic, such as providing improved level of service for other modes and contributing to place-making within communities.

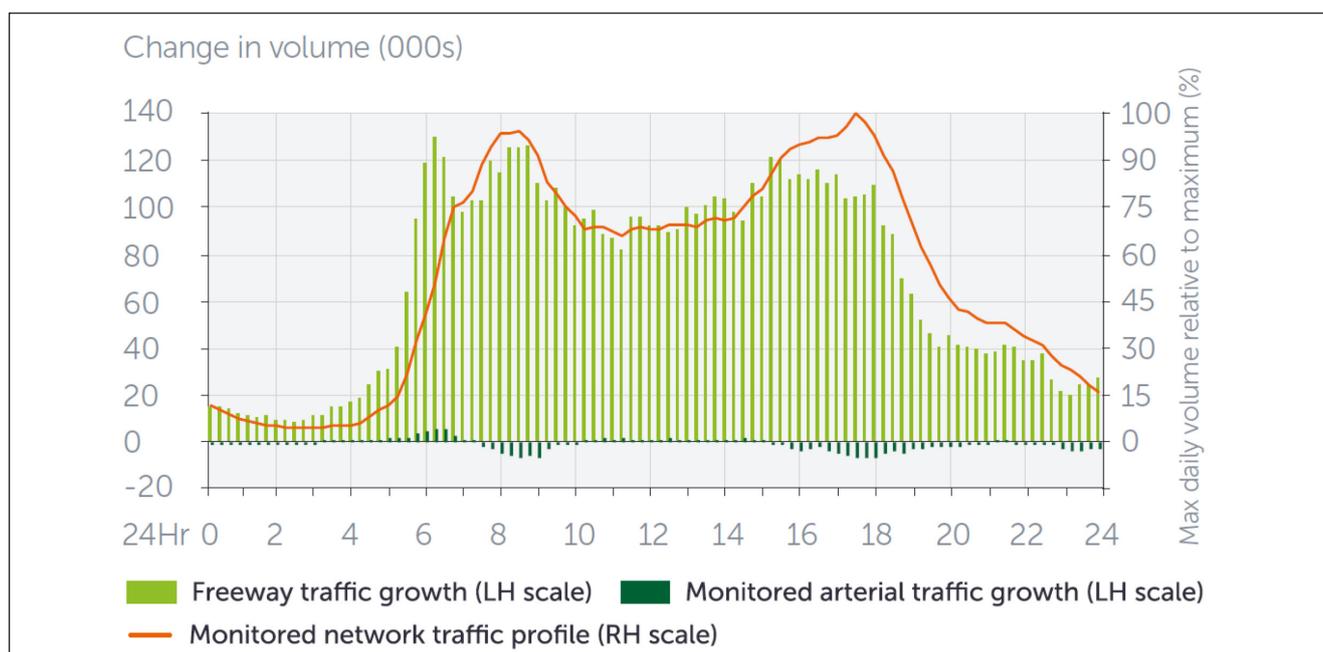


Figure 2.1 Distribution of traffic growth (freeways and arterial roads, from Traffic Monitor 2012/13)

2.2 What do road users value?

VicRoads Customer Service Strategy puts customers at the centre of its business, and as a network manager this means meeting the needs of all of the different road users on its network and improving their journey experience on one seamless road network with multiple road operators including on-road public transport operators.

When measuring the level of service for road users, we no longer think just about the level of delay and safety, but also the reliability and comfort of travel on a route. Whilst travel conditions may be considered acceptable from an operational performance perspective, we need to ensure our customers perceive this to be the case and are satisfied with the service provided.

This means only intervening when required to improve their travel conditions and without causing undue confusion or stress. It also means providing a seamless and consistent driving experience so that regardless of whose road they are driving on, they always know what to do and have a good journey experience from start to end. Active management interventions on one route may impact on others, and a continuing operational response may be critical to both addressing the original problem and preventing it from moving to another location on a route.

Traveller information is an important component of journey management and improving customer satisfaction. It can inform drivers of the cause and nature of changes in travel conditions, and assist with travel choice through information on travel times and alternate routes to avoid delays. A multi-organisational approach is critical to providing effective journey management and traveller information.

The active management of Melbourne's motorway network must therefore provide for the needs of road users, being reliable, efficient, safe, predictable and comfortable travel. VicRoads' Managed Freeways Policy (September 2013a) provides specific guidance on this, stating that:

A managed freeway meets the road user's expectations for safe and reliable travel on a preferred traffic route by providing:

- a safe travel environment through speed limits that reflect conditions (where appropriate);
- travel at satisfactory but not necessarily free-flow speeds throughout the day;
- reliable travel, with only a small buffer required in trip planning;
- information about freeway incidents and alternative routes prior to entering the freeway;
- information about freeway incidents and advised actions to take when on the freeway; and
- a clear indication of which lanes are closed to traffic due to an incident or works (where appropriate)

These same drivers can also be seen in a recent project Investment Logic Map (ILM) for an outer section of the Monash Freeway, shown in Figure 2.2. The benefits are mapped to key performance indicators (KPIs) for the motorway network.

The active management of the road network is driven in real-time by supporting data, and likewise the ILMs for active management initiatives should benefit from the use of objective data. Clear analysis should be used to determine problems and opportunities and the weighting of their importance. Objective analysis should also support the selection of changes and assets that form part of the solution.

Focussing on what matters to road users means focussing on outcomes, and that is an essential aspect of effective active management of the road network. The most visible aspect of active management is the roadside infrastructure, such as overhead lane use and speed signs and ramp signal lanterns, however this infrastructure represents only part of what is needed to deliver outcomes. This infrastructure needs to be part of a broader and ongoing operational management activity.

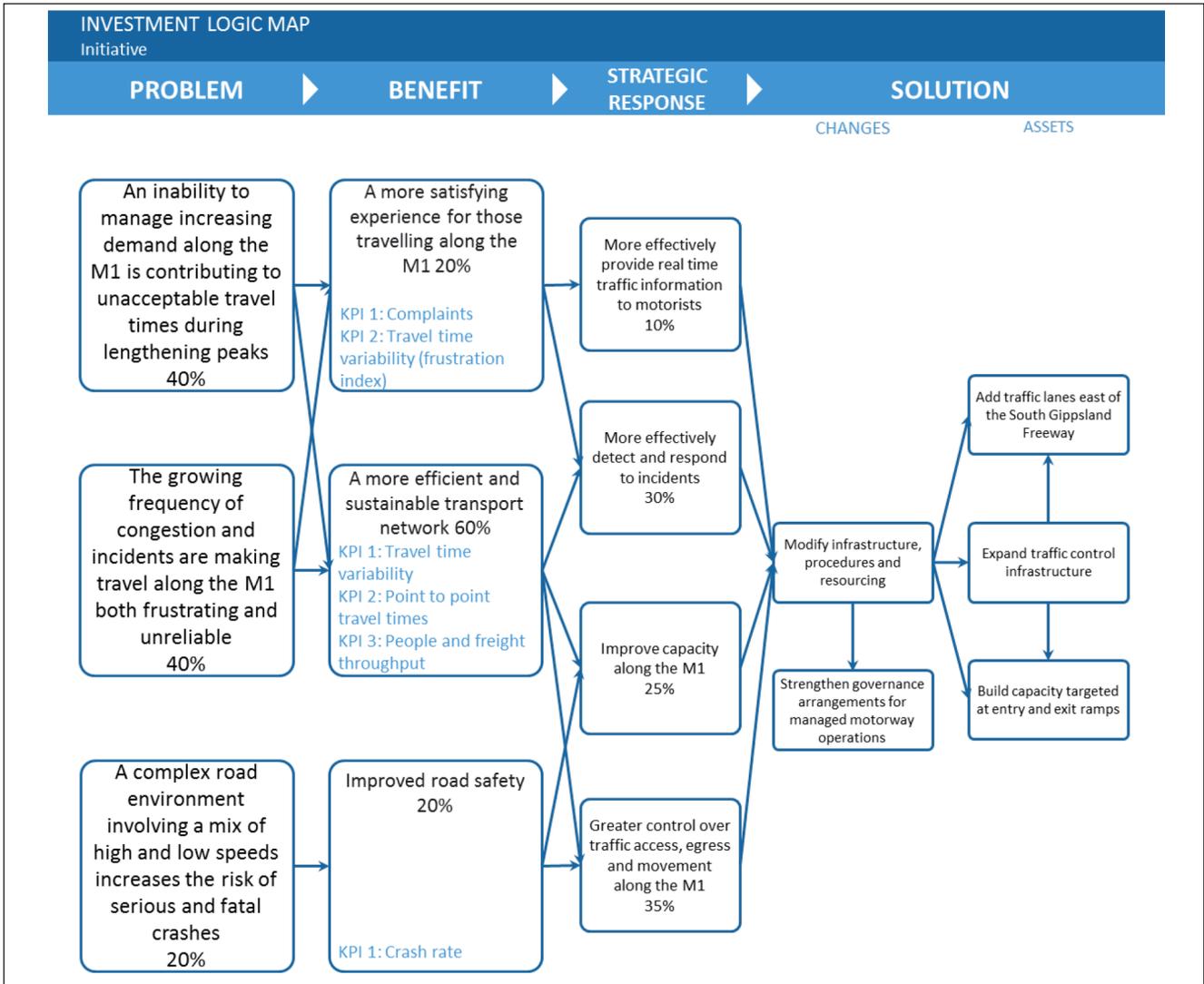


Figure 2.2 Investment Logic Map for M1 Managed Motorway – Warrigal Road to Clyde Road

2.3 Maximising infrastructure productivity, safety and performance

The ILM in Figure 2.2 includes the benefit of a more efficient and sustainable transport network and the associated key performance indicator (KPI) of people and freight throughput. This means that in addition to the value created for individual road users, the active management of Melbourne’s motorway network has the important community function of getting more productivity from these expensive assets.

Figure 2.3 compares the growth of road travel demand over a ten year period with the growth in road lane kilometres (capacity or supply). This faster growth rate of demand over supply occurred despite strong investment and is likely to continue. This relationship means that in order to help maintain network performance, it is necessary to increase the productivity of the existing infrastructure as well as to better manage demand for the road network.

Motorways and tollways in Melbourne carry around 39% of the total arterial road traffic, although they comprise only 7% of the arterial road network length. Heavily trafficked motorway sections with four or more lanes are regularly experiencing flows greater than 200,000 – 210,000 veh/day on weekdays, for example on Monash Freeway between Stephensons Road and Huntingdale Road, West Gate Bridge, Tullamarine Freeway near Bell Street, and the Western Ring Road near Tullamarine Freeway. High demand is not just limited to peak hours; weekend volumes can reach 95% of Monday traffic volumes (the lowest volume weekday).

These figures do not even reflect the true demand for current use of the motorway network; as traffic volumes approach and exceed operational capacities there is flow breakdown causing congestion on the network. This manifests itself as sudden drops in throughput and travel speeds that are usually sustained throughout the peak period, meaning that demand for use of the facility is ‘unsatisfied’. In the example in Figure 2.4, flow breakdown on the Kwinana Freeway (northbound) in Perth results in a drop in speed of over 60 km/h and significant decrease in throughput. When considering the number of freight vehicles using the route, it is estimated that this equates to an average unsatisfied freight demand of 1,800 tonnes per day.

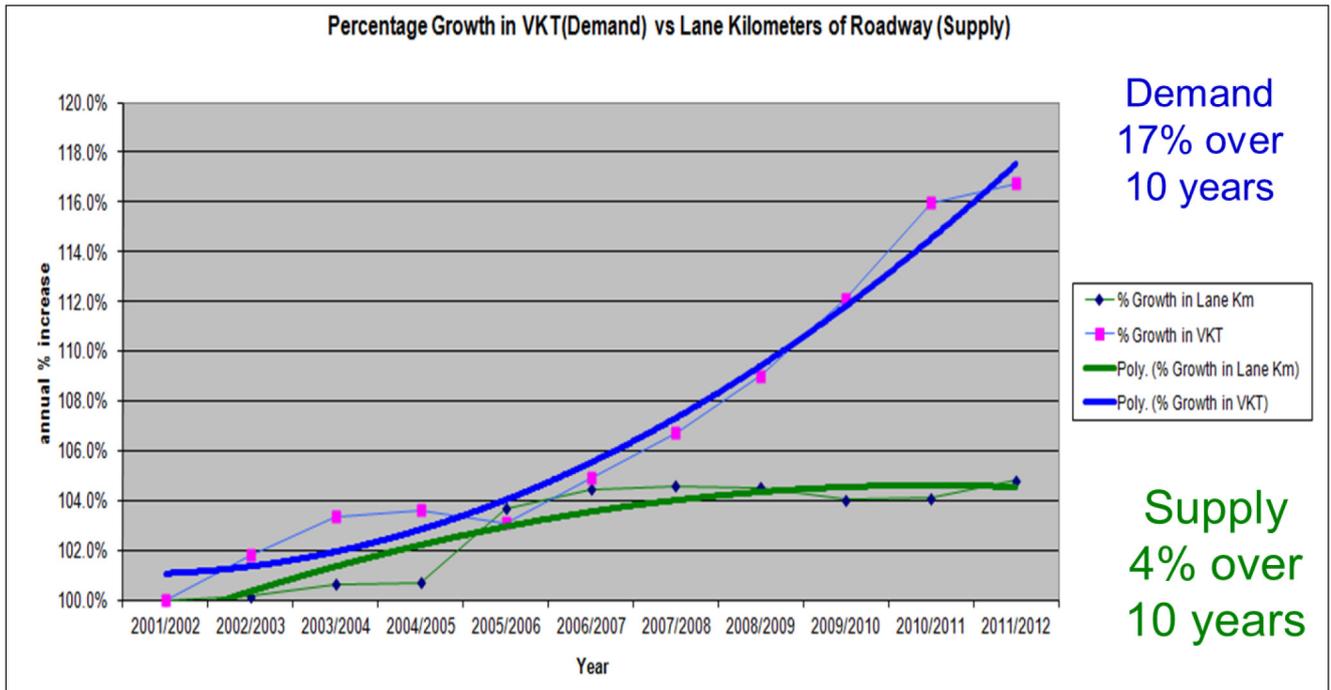


Figure 2.3 Demand and capacity growth on Melbourne’s road network

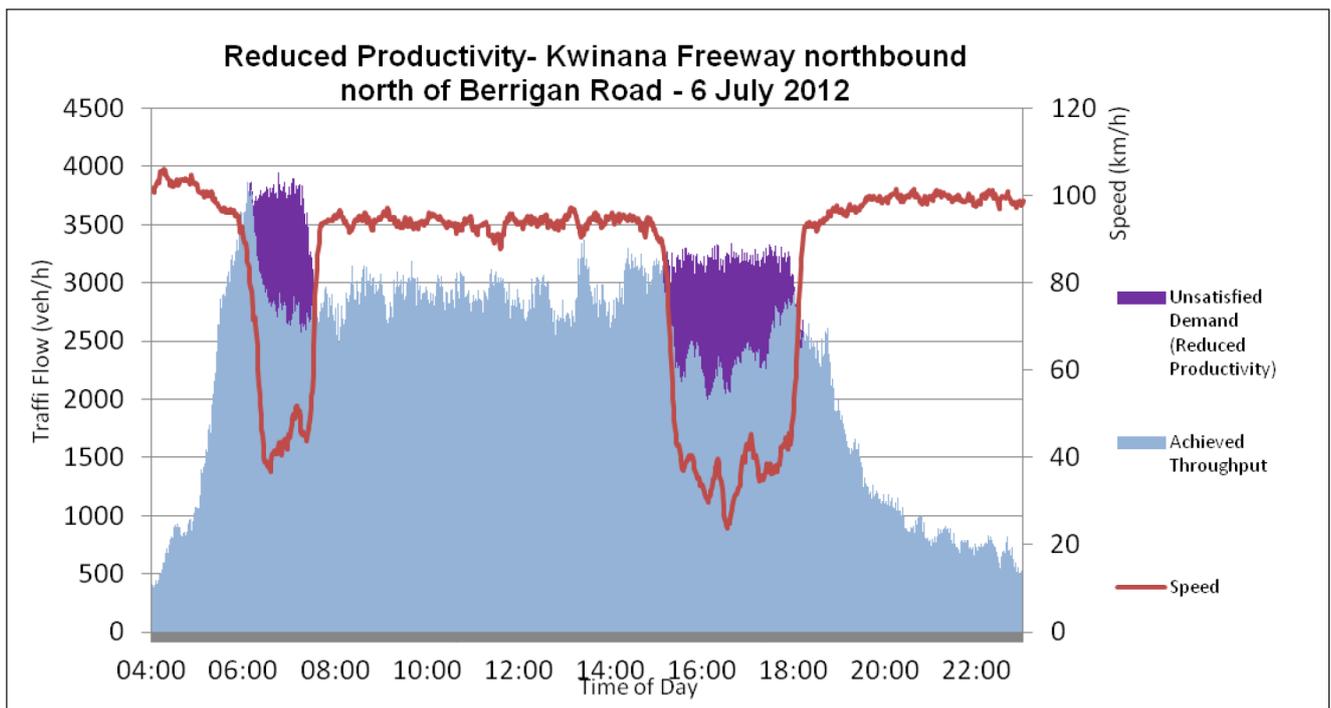


Figure 2.4 Reduced productivity during peak periods on Kwinana Freeway, Perth WA

Since high productivity is achieved when both speed and flow are maintained near maximum values (i.e. near free-flow speed and capacity flow), this represents sub-optimal performance with a negative impact on road users such as excessive and unpredictable travel times. With many motorways in Melbourne also carrying high volumes of heavy vehicles (10 to 25% of total volumes), this also means a significant impact on freight productivity.

Empirical research demonstrates that too high entry ramp flows contribute to turbulence and flow breakdown on the mainline, resulting in reduced operational capacity and losses in productivity.

Traffic congestion is also contributing to crashes on the freeway due to stop-start conditions and increased lane changing. Figure 2.5 demonstrates that on the Monash Freeway (Warrigal Road to Clyde Road), crashes occur most commonly in the peak periods when traffic speeds are lower and throughput is decreased.

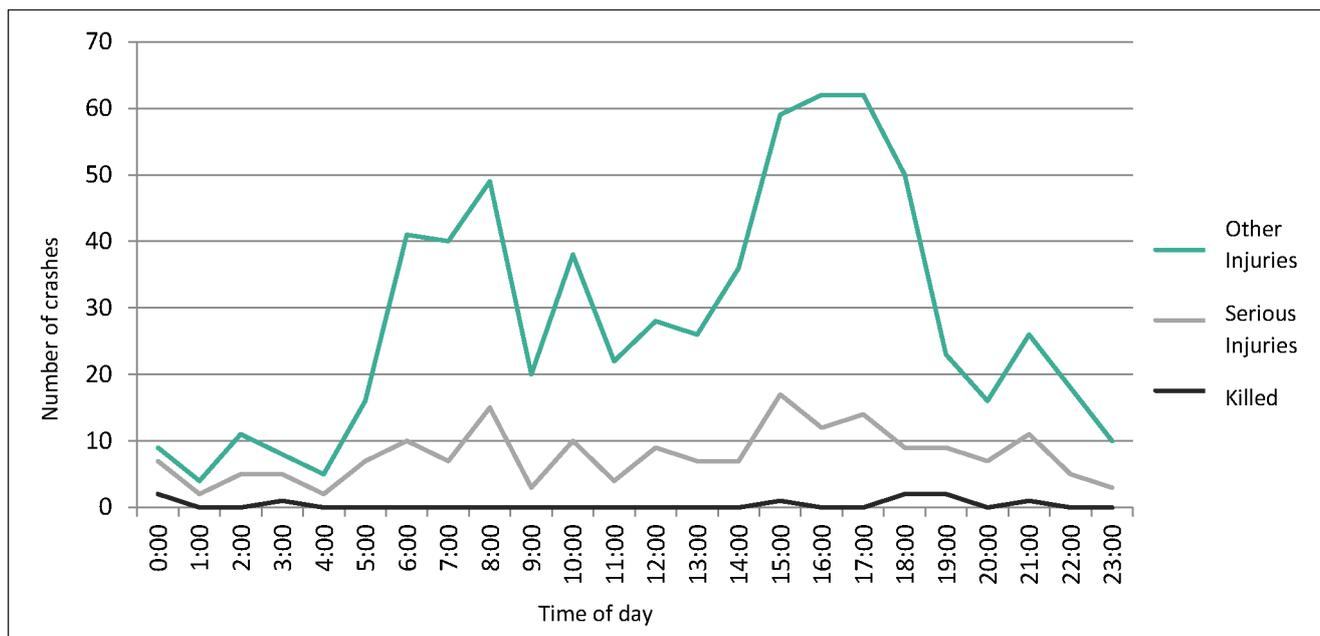


Figure 2.5 Daily profile of crashes on the Monash Freeway (Warrigal Road to Clyde Road), VicRoads

Even minor crashes can have a big impact on a motorway’s recovery from congestion, and due to the high volumes it will inevitably result in injuries and fatalities.

As the Victorian population and economy grows the demand for use of the motorway network will continue to increase putting even more pressure on the system to achieve maximum utilisation. Modelling activities have predicted that over 270,000 veh/day will be using some motorway sections by 2031, which will mean that **the motorway will need to operate some 12 to 13 hours a day at or close to maximum operational capacity.**

Active management can assist in unlocking the ‘lost’ motorway productivity by managing flows so they are sustained at levels closer to operational capacities throughout the peak period without flow breakdown. This will result in smoother traffic flows that improve safety and efficiency for road users. Coordinated ramp signals are a key active management tool to achieve this, along with other tools that provide additional capacity enhancements and improved incident management capability. Further detail regarding the traffic flow theory behind ramp signalling is provided in Section 3.1.4, as well as the VicRoads Managed Freeways: Freeway Ramp Signals Handbook (FRSH) (2013c).

VicRoads’ Managed Freeways Policy (September 2013a) recognises this need for improved infrastructure productivity, stating that:

A managed freeway meets the road manager’s need for a maximum productivity facility which maximises transport outcomes from the asset (e.g. “sweats the asset”) by providing:

- *managed traffic flow to minimise flow breakdown; and*
- *incidents and disruptions detected and verified to enable effective management and quick clearance.*

2.4 Proven results

Active management is implemented in various forms by road operators across the world, who have reported demonstrable results in improving motorway performance.

Melbourne’s M1 Monash Freeway Upgrade project included the implementation of a coordinated ramp signalling system, with signals at 64 ramps coordinated via the HERO control strategy, as well as lane use management to implement all lane running (following civil upgrades) and traveller information systems.

Due to the extent of civil improvements included within the M1 Upgrade, many post-evaluation studies have struggled to single out the benefits of individual components such as the coordinated ramp signals compared to additional lanes. To provide this ‘apples with apples’ style of comparison of the benefits of active management (primarily coordinated ramp signals) on this route, analysis has recently been undertaken to look at per lane throughput along the freeway route. This analysis compares performance in October 2007 (before the upgrade) with October 2013 (after the upgrade), covering a 25.5 km section, between the South Gippsland Freeway interchange and Toorak Road. There was a total of 13 interchanges along the corridor in the before case and 14 in the after case due to the addition of the (currently unmetred) interchange with the EastLink tollway in late June 2008.

Table 2.2 Benefits of active management as part of the M1 Upgrade

Route averages	Before (October 2007)	After (October 2013)	Increase	%
Inbound 6-9am volume	1,476 veh/h/lane	1755 veh/h/lane	279 veh/h/lane	+19%
Inbound 6-9am speed	63 km/h	75 km/h	12 km/h	+19%
Outbound 3-6pm volume	1,402 veh/h/lane	1,627 veh/h/lane	225 veh/h/lane	+16%
Outbound 3-6pm speed	58 km/h	74 km/h	16 km/h	+28%

The results in Table 2.2 show route average volumes and speeds, across the full 25.5 km route. Route average volumes are lower than maximum or bottleneck volumes, as demand along a route is rarely in perfect balance with the infrastructure (i.e. the number of lanes) along that route. Likewise, route average speeds are higher than the speed at the bottleneck locations, and the lower before speeds are associated with greater variability of speed along the route.

The route average speeds in the after case (October 2013) are around the 75 km/h range, which indicates one of the challenges in demonstrating benefits of active management initiatives, being that they make significant improvements in performance but without fully 'resolving' congestion unless there are appropriate operational strategies.

The use of route and network measures is necessary to assess the benefits of route and network optimisation; measures at a single location are not necessarily indicative of wider performance. The ultimate measure of the efficiency of any motorway system is the throughput of that system, which becomes outflow at exit points from that system.

The benefit of another key Managed Motorways treatment was explored through analysing before and after results on the West Gate Bridge in Melbourne. As part of the M1 Upgrade, the bridge was converted from four to five lane carriageways on the existing pavement through re-marking and adding integrated speed and lane use management to provide a safe operational environment. More recently, this type of approach has become known as 'All Lane Running' (ALR) due to extensive UK development and implementation activities for their Smart Motorways program.

The West Gate Bridge is a critical transport asset for Melbourne worth several billion dollars and is a key access and freight route for the city; at the time widening the bridge using traditional methods or building an alternative river crossing was proven to be unaffordable.

Following the M1 Upgrade works, the bridge is now carrying more traffic than previously. As illustrated in Table 2.3, during the morning inbound peak (6:00 to 9:00 am), the flow across the bridge has increased by 5,616 vehicles (three hours of 1,872 per hour) and the average volume per lane has increased rather than reduced despite narrower lanes and shoulders than previously.

Table 2.4 demonstrates that a similar result is seen in the afternoon outbound peak (3:30 to 6:30 pm).

Table 2.3 Inbound before (2007) and after (2013) West Gate Bridge peak traffic volumes; Tuesday to Thursday, excluding incidents and outliers

6-9am inbound, midweek	Before (Oct 2007)	After (Oct 2013)	Increase	%
Average peak volume per lane	1,705	1,739	34	2.0%
Average peak volume per carriageway	6,822	8,694	1,872	27.0%

Table 2.4 Outbound before (2007) and after (2013) West Gate Bridge peak traffic volumes; Tuesday to Thursday, excluding incidents and outliers

3:30-6:30pm outbound, midweek	Before (Oct 2007)	After (Oct 2013)	Increase	%
Average peak volume per lane	1,830	1,850	20	1.1%
Average peak volume per carriageway	7,316	9,249	1,933	26.4%

The benefits from the M1 Upgrade highlight the substantial value that active management can provide compared to more traditional road investments. The M1 Upgrade in Melbourne had a total capital investment of \$1.4 bn, which included around \$1.3 bn of civil works to rebuild interchanges and add a lane in each direction along with around \$0.1 bn of ITS capital works to actively manage the motorway.

Figure 2.6 highlights that active management has enabled 16 to 19% more traffic per lane to be sustained along the route following the upgrade. This additional traffic flow is equivalent to adding around 0.7 further lanes, with the opportunity for this to increase further with improved management of the whole corridor. The incremental ongoing cost of the ITS is less than that associated with civil works of that scale, however it represents a very different balance of costs within the life-cycle. The need for greater proportional operational/recurrent funding for active management relative to traditional road capital investments does not always align well with road authority funding cycles and approvals, and needs to be addressed as part of the strategic planning for Managed Motorways.

The 1,700 to 1,800 veh/h/lane of throughput shown in Figure 2.6 represents the average volume along a route and throughout a 3 hour peak period. This number appears lower than figures sometimes used for motorway lane capacity as capacity figures are normally given for a peak time and location.

The M1 Upgrade business case was expected to increase peak hour carriageway throughput by 50%, although this was to be achieved only by adding one lane each direction, increasing throughput by 33%, together with the CRS that was expected to deliver the remaining 17%. In retrospect, there is now additional understanding of a general relationship between the number of lanes and lane flows and it's been observed on the Melbourne freeway network that as you add lanes to a freeway the actual per lane flows decrease, primarily due to the increased turbulence resulting from additional lane changing. Hence, the 33% should have been assumed to be closer to 25%. However, Figure 2.6 shows that despite the over-estimation of the capacity increase as a result of the extra lane, the peak hour carriageway flows for the freeway section between South Gippsland Freeway and Toorak Rd has increased by an average of 56%; this is made up from an increase of 59% in the inbound direction during 6:00 - 9:00am and 54% in the outbound direction at 3:00 - 6:00pm.

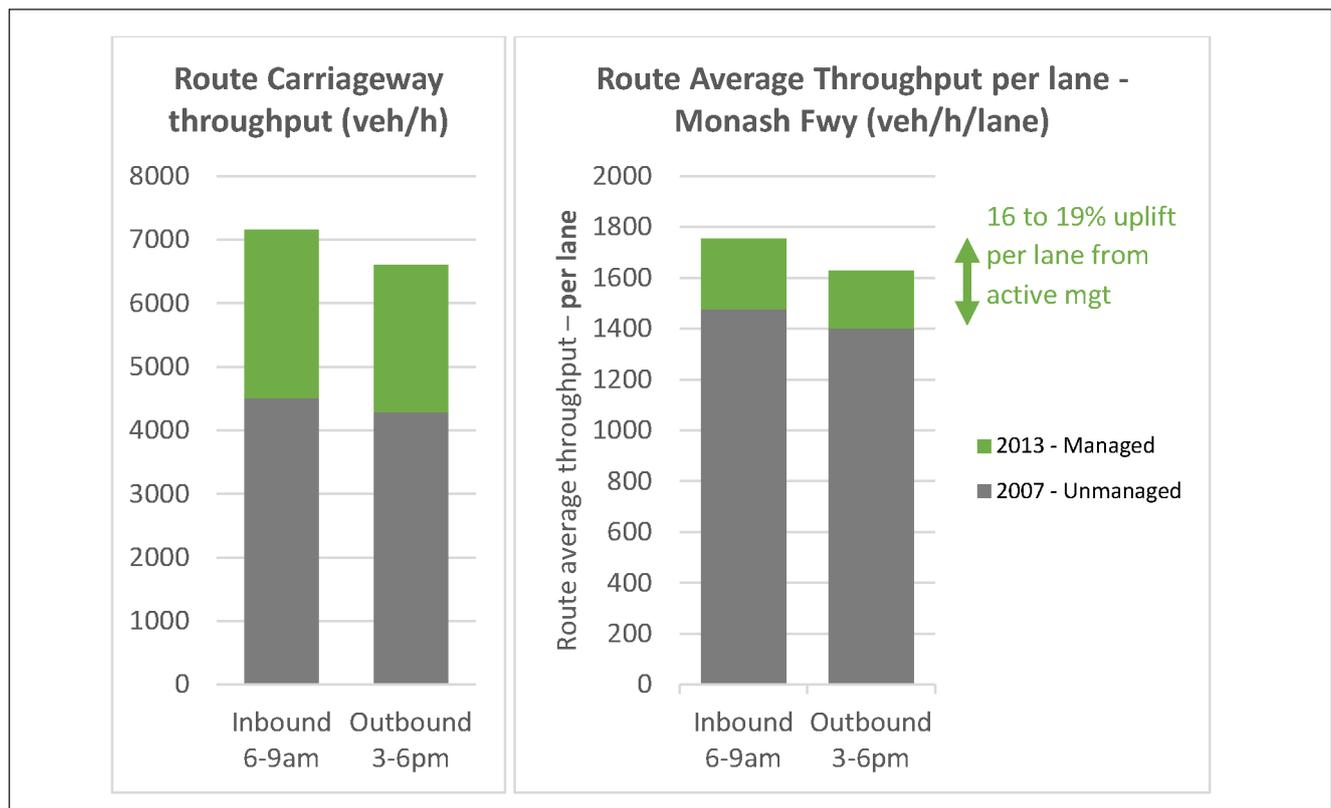


Figure 2.6 Improvement in route carriageway throughput and route average throughput on the Monash Freeway

Although Figure 2.7 can be challenging to interpret, the blue areas represent flows in excess of 2,000 veh/h/lane, showing that for much of the peak and length of the route this higher performance is achieved.

The results of any evaluation are dependent on the specific implementation of the active management tools (algorithm and parameter settings) as well as the demands on and characteristics of the route in question. For this Victorian Managed Motorways Framework, this section has therefore concentrated on results achieved on Victorian motorways using Victorian systems. Further details of the two M1 Upgrade case studies discussed in this section are provided in Appendix A.

In general, the experience of Managed Motorways is positive and outside of Victoria, there are many evaluations of existing active management schemes that evidence the range of benefits that can be realised. These include:

- Twin Cities, Minnesota – the local ramp metering system installed on 433 ramps on the freeway network was switched off for two months and performance impacts evaluated;
- Various other US evaluations of the traffic and safety improvements achieved after installation of ramp metering (e.g. Seattle and Denver);
- M42 active traffic management project, UK – one and three year evaluations of the operation of part-time hard shoulder running implemented with LUMS, VSL and with traveller information; and
- Various evaluations of dynamic VSL and traveller information/rerouting projects worldwide that enable speed harmonisation, queue protection and congestion and demand management.

A summary of the results from these international evaluations is included in Appendix A. These results confirm that Managed Motorways tools have the potential to deliver very high benefits, providing they are applied in a targeted manner to achieve specific outcomes.

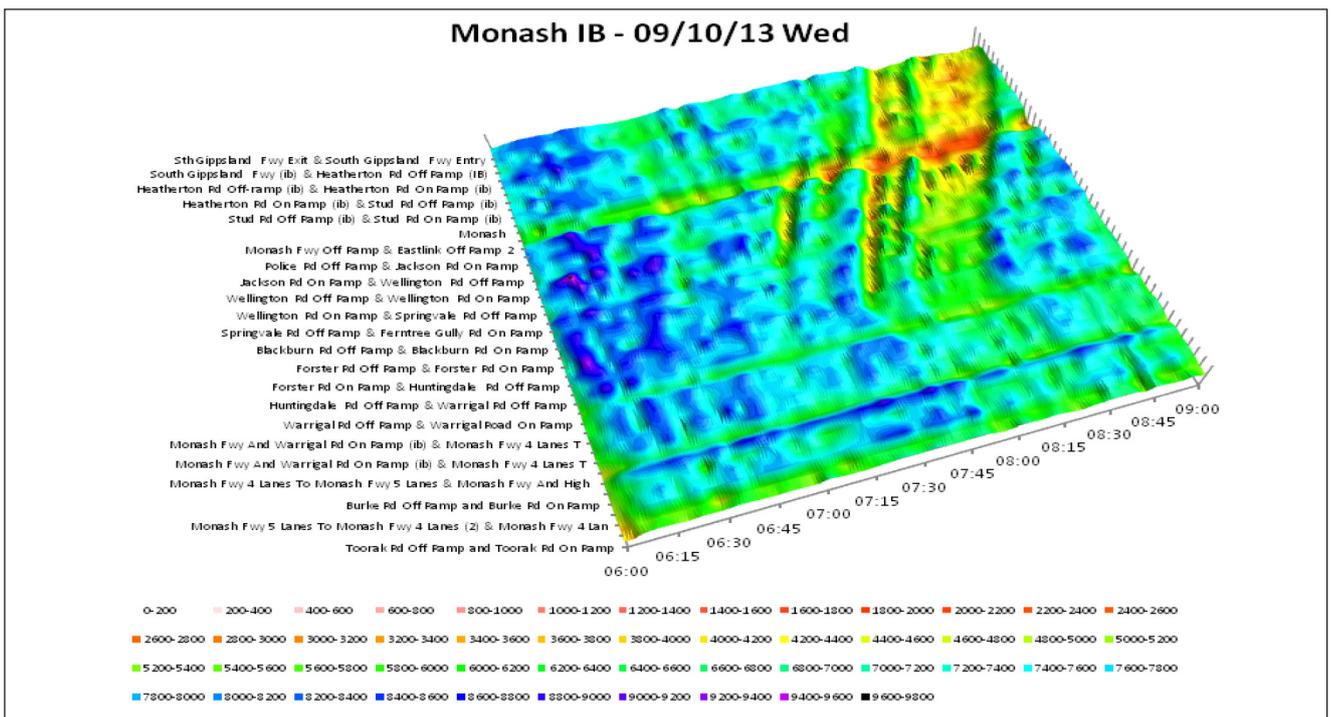


Figure 2.7 Route performance snapshot showing high volumes (blue) and areas under pressure (red)

Section 3

Summary – Levels of active management

The Victorian Framework for active management is based on a layered approach that builds in complexity and the level of control and integration between systems and networks.

The layers of active management are defined as follows:

- Network monitoring and intelligence – the collection of data on network conditions and issues that is used to trigger traffic control interventions, provide critical inputs for dynamic optimisation control algorithms and support calculations of travel times for traveller information, as well as support network performance reporting;
- Traveller information – the provision of information to road users on motorway travel times and conditions that can support their mode and travel choices on the motorway even before they reach it, thereby also helping road operators to manage demand to the motorway network particularly during incidents and congestion;
- Traffic management and control interventions – discrete traffic control actions on the road network that are initiated in response to incidents, congestion and planned network activities;
- Route optimisation – continuous and automated fine-level adjustments to dynamic algorithms that tune performance of a route towards a defined objective target; and
- Multi-modal network optimisation with journey management – Simultaneous optimisation across network links and different user groups to achieve a ‘one network’ optimum that also optimises user journeys.

While VicRoads has made progress in the first four layers, the fifth is considered as emerging practice and this Framework goes some way to identify how it can be achieved.

This section provides further description of each of the layers of traffic management, including insight to the theoretical basis behind optimisation control algorithms as well as some of the challenges that will be faced in achieving the complex goal of multi-modal network optimisation. Target states for each level of active management are provided to help illustrate the intended outcomes.



3. Levels of active management

3.1 Introducing the different levels of active management

There are a number of ways in which VicRoads can and does work to maximise the productivity and safety of its freeways (motorways) through active management. In many cases, more than one of these methods is used on a section of freeway and many must be performed together due to critical interdependencies.

VicRoads' previous guidelines for Managed Freeways (see References in Section 10) identify three different categories of tools: intelligence, information and control. This Framework extends this categorisation after reflecting on current and future needs, to further define intelligence and information and to identify three different levels of control (refer to Table 3.1). The first four levels of this new five level model better reflect the full range of active management methods used and the fifth layer highlights an area of emerging practice.

Table 3.1 Comparison between levels of active management and previous guidelines

Categories of tools in previous Managed Freeway Guidelines	Levels of active management in this Framework
Intelligence	Network monitoring and intelligence
Information	Traveller information
Control	Traffic management and control interventions
	Route optimisation
	Multi-modal network optimisation with journey management

The split introduced in the control tool category between intervention and optimisation tools is an important change, as it recognises the differences between intervention measures that make relatively infrequent step changes in operation of the road to alter the operational regime or operational state and those optimisation measures that use continuous fine-tuning to maintain stable traffic flow near to the edge of instability at optimal levels.

Sections 3.2 and 3.3 provide simple representations of the layers of active management for both the overall road network and motorways. The remainder of Section 3.1 further introduces these layers of active management.

3.1.1 Network monitoring and intelligence

Network monitoring and intelligence is the foundation of active management, providing the information needed to manage the road network. In some cases, network monitoring and intelligence provides direct outputs, such as daily and monthly reports on route/network and system performance. In most cases however, network monitoring and intelligence provides inputs into other levels of active management.

The current state of practice for motorway management uses detectors in the road, which may be inductive loops, wireless magnetometer studs or non-intrusive detectors. Emerging vehicle and mobile phone probe technologies, as well as e-tag data from toll roads, provide additional sources of data that are particularly useful for determining travel times and movement patterns. In addition to data on traffic densities, another important source of intelligence is visual information such as that provided by CCTV cameras.

The requirements for network monitoring and intelligence are driven by the purpose(s) for which the collected data is used. Functional and technical requirements for network monitoring and intelligence should therefore explicitly state the purpose for which the data is currently used and/or may be used in the future to ensure that it meets these needs.

The information gathered in network monitoring and intelligence is used in all phases of the active management lifecycle, as described in Figure 3.1.

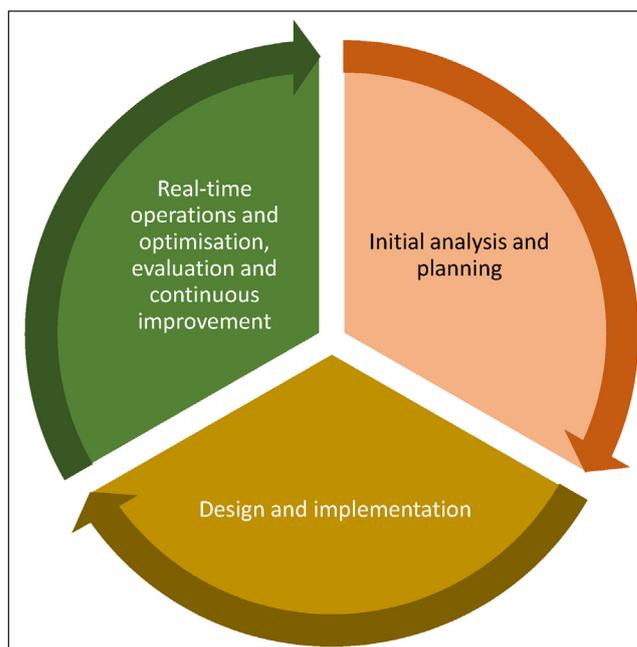


Figure 3.1 Lifecycle of active management

3.1.2 Traveller information

The traveller information function assists road users to reduce the impacts and stress of unreliable travel and to make informed decisions about their travel, for instance route choice and time of travel. An overall traveller information strategy for freeway users should consider three time periods for the provision of information:

- Pre-trip (e.g. before leaving home or work including mode choice);
- En-route, but before entering the freeway; and
- En-route, after entering the freeway.

Traveller information can be far more flexible than control-based intervention and optimisation methods due to the potential to tailor what information is provided, to whom and when. Unlike intervention and optimisation however, the response of road users to the information they receive is voluntary. Responses to traveller information are highly variable between users, even in cases where the information could directly improve that road user's travel.

Traveller information relies upon the network monitoring and intelligence layer of active management to provide the data necessary to generate traveller information. For example, to calculate travel times, to detect and verify the location of congestion and incidents and to provide a relative indicator of the state of traffic flow on a route (e.g. light, medium, heavy, major delays or seek alt route).

There are multiple methods of dissemination of traveller information and these are continuing to change with new technology, including a trend towards more proactive and personalised traveller information. Information provided to in-vehicle systems and smartphones will grow in relative importance as they achieve increasing penetration rates and provide more flexibility in influencing mode and travel choices. However, established methods such as roadside signs and radio break-in in tunnels will remain important during incident conditions for a number more years due to their greater potential to reach all road users that are directly affected by the incident.

There are potential critical dependencies on traveller information for it to support the active management functions of traffic management and control interventions and route and multi-modal network optimisation. Traveller information assists to alert road users to changed conditions and to encourage compliance by explaining the reasons for the change. Traveller information also assists to support route diversion activities by encouraging road users to avoid the most congested sections of the road network, particularly during times of unusual congestion including incidents.

Real time traveller information services are required to inform on-road public transport operators about abnormal traffic conditions so they can in turn provide reliable real-time information services direct to their customers.

3.1.3 Traffic management and control interventions

Traffic management and control interventions alter the operational regime or operational settings of a section of road, route or network. Some interventions may be small changes and others will be much larger changes. Interventions can be used in response to incidents and to assist managing events, however they are not limited to this and can also be used due to other changes in traffic conditions. Examples of traffic management and control interventions currently used include:

- Opening a part-time lane to traffic, whether it be on a fixed-time schedule or in response to a situation or changing traffic conditions;
- Reducing speed limits and/or closing lanes due to an incident, event or works;
- Reducing speed limits due to adverse weather conditions;
- Reducing speed limits due to a detected queue or incident (often called queue protection);
- Closing a freeway entry ramp to assist incident management; and
- Changing the allowable users of a lane (e.g. allowing T2 vehicles to access a bus lane).

Traffic management and control interventions vary in their level of automation, for example:

- Manual situational awareness, human (manual) generation of response, system activation after human approval;
- System identified situation, system recommendation of manually developed plan, system activation after human approval;
- System identified situation, system generated recommendation based on rules, system activation after human approval;
- System identified situation, system generated recommendation based on rules, system activation;
- Time-based activation of plan, either with or without human approval; and
- Other combinations of the above.

All the examples above of traffic management and control intervention relate to actions on a freeway itself, however actions can also occur on the arterial road network either in isolation or in support of freeway actions.

3.1.3.1 Responding quickly to incidents

Austrroads' research on incident management (e.g. AP-R304-07 Traffic Incident Management: Best Practice, 2007) highlights the need to respond quickly to incidents, with the duration of the impact of incidents roughly equal to five times the duration of the incident itself. There are many demands on operators at the Victorian Traffic Management Centre that mean that systems are needed to assist in quickly identifying and generating responses to incidents to reduce the time taken to respond.

Recent (2014) investigations by the Queensland Department of Transport and Main Roads in Brisbane have shown the potential of system identification of queued traffic not only to reduce response times, but also to increase the proportion of traffic queues detected for response. The project configured the STREAMS Queue Detection/Queue Protection algorithm to use loop detector data to operate in 'Information Only' mode, where the algorithm made recommendations for speed reductions, but did not implement them. This allows a valid comparison of the initial response time, comparing previous manual practice by operators (assisted by CCTV cameras, phone calls and other means of gaining awareness) with the automated algorithm for queue detection and protection.

Data was analysed across 13 weeks over a 22 week period during which the response times to 135 confirmed traffic queues were recorded. The time taken for operators to detect and respond to these queues was compared with the response time of the automated algorithm. There were no false alarms (non-existent queues) detected with this particular automated algorithm, which is an important result as false alarms have been a major weakness of some automated detection approaches. The summary of the results from the trial is shown in Table 3.2 and shows the potential offered by automated algorithms; the algorithms detected 22% more queues and were on average almost 28 minutes quicker than operators. It is important to note that this STREAMS Queue Detection/Queue Protection algorithm seeks to identify queues, including those caused by incidents rather than directly identifying incidents. As such, incidents are only identified in cases where traffic queues result.

By using automated detection systems such as this particular queue detection approach, the focus of operators in the Victorian Traffic Management Centre environment can be concentrated on the activities where human input can provide the greatest value. This support from automation will continue to become more important as the complexity of the road management activities overseen by operators continues to increase.

Table 3.2 Difference in response times between manual and automated detection

	Manual approach	Automated queue detection
Average time to detect	32.2 minutes	4.3 minutes
Queues detected	86 (64%)	116 (86%)

3.1.3.2 Maximising user and community outcomes

In order to get the best productivity from the road network, the use of restrictive traffic management and control interventions should be limited to when those restrictions are justified and necessary. Reducing speeds and closing lanes reduces the capacity of the freeway and the use of these approaches should be limited to the bare minimum necessary for safe operation of the freeway. This is explored more in the general operating principles for use of the Managed Motorways toolkit that is included in Section 4.2 of this Framework.

3.1.4 Route optimisation

The optimisation of a route is achieved through continuous and automated fine-level adjustments to tune performance of that route towards a defined objective target. Successful route optimisation requires significant analysis and planning to set up as well as monitoring, learning and adjustment to ensure continued achievement of the desired performance. As route optimisation is reliant on algorithms to achieve the automated and continuous adjustment, it is essential that these algorithms are based on sound theory that has been well-tested in practice. The theoretical basis of VicRoads' route optimisation on freeways is further explored in Section 3.1.4.2.

For route optimisation to be fully effective it must cover the full length of logical routes. In some cases there will be a number of logical routes on a road, however in other cases logical routes can be very long and cross jurisdictional boundaries. Even in cases where logical routes are short, effective management at the limits of capacity and stable flow may require a number of logical routes to be combined into one to enable sufficient effective control.

Route optimisation is not limited to uninterrupted flow routes such as freeways. VicRoads has undertaken route optimisation on arterial roads to varying degrees, including widespread use of adaptive signal control through SCATS. The optimisation problem (or function/task) on arterial roads differs from freeways and requires its own theoretical and practical basis.

3.1.4.1 Optimising for different modes

VicRoads' SmartRoads outlines an approach to network operations that explicitly considers the different needs of different road user modes and drives management of the network to reflect those different needs. SmartRoads caters for pedestrians, cyclists, trams and buses, freight and general traffic. Melbourne's arterial roads are identified to have many different priority uses for different locations and times of day. The freeway network is more homogenous in its priorities, with the freeways assigned a strong priority for freight and general traffic, as well as public transport where relevant (such as the Eastern Freeway). Within the urban transport network, the freeways are given the function of providing for freight and general traffic movements to the maximum extent possible, relieving some pressure on the arterial road network to serve its more diverse functions.

This clear distinction between the near homogeneity of priorities for the freeway network and strong variety of priorities for the surface road network (arterial and other lower order roads - refer Section 1.4) directly impacts how the performance of these routes should be optimised and the relevant objective targets for that optimisation.

Freight, public transport and general traffic all share similar operational objective targets for optimisation – reliability and travel speed at an individual road user level and productivity at the community level. On an optimised freeway, there is no advantage for these individual measures (i.e. reliability and travel speed) in providing dedicated lanes as all traffic is moving at an acceptable rate. On the contrary, providing dedicated lanes on the freeway for certain modes is likely to reduce productivity as there is unlikely to be a matched distribution of demand to provide full use of the designated lanes. The entries and exits to freeways are the locations where priority can be provided on optimised (managed) freeways, and this is recognised in Section 3.9.1 of VicRoads Managed Freeways Guidelines (2014). Although there are examples of priority lanes on Melbourne freeways, most notably on the Eastern Freeway, this relates to a situation where the freeway terminates on an surface road network and the lanes function most strongly as very long exit priority lanes.

3.1.4.2 Theoretical basis for freeway route optimisation

Since 2005, VicRoads has based its Managed Motorways operations on contemporary traffic flow theory, where traffic flow is no longer considered to be deterministic but rather stochastic. The stochastic nature means there is a random element to the probability distribution of capacity that may be analysed statistically but not predicted accurately – refer to Section 2 of the Managed Freeways: Freeway Ramp Signals Handbook (FRSH) (2013c) for more information. This understanding of the stochastic nature of freeway traffic flow is complemented by an appreciation of:

- The physics of traffic flow is akin to a modification of the gas kinetic theory;
- The phenomena relating to wave theory (forward and backward moving waves);
- The perturbations that cause the traffic flow breakdown phenomena resulting in loss of throughput and efficiency (small disturbances that occur in traffic flow at the one second level);and
- The interventions required for the freeway to recover from flow breakdown, and that recovery mechanisms are different to breakdown mechanisms.

Over the past decade VicRoads has worked closely with the following referenced authors: M.Treiber, W. Brilon, M. Papageorgiou and D Helbing, and have also studied B.S Kerner's work outlined in his book titled 'The Physics of Traffic' (2004). A thorough understanding of the work of these authors is paramount to understanding VicRoads' approach to freeway optimisation, including use of the HERO LIVE algorithm for coordinated ramp metering.

In addition, over this time VicRoads developed further understanding of the dynamics and complexity of control systems required to bring about enhanced traffic control. This has led to VicRoads developing and applying industrial control methods including real time statistical analysis, feedback regulators and optimisation tools, which are now well-established in the Managed Motorways control systems.

Contemporary traffic flow theory demonstrates a fragile knife-edge control phenomena where a freeway can move from stable to unstable traffic conditions in a matter of seconds. Traffic flow is akin to a modified gas kinetic model; when flow becomes unstable the vehicles (molecules) get closer together and get excited resulting in a rapid increase in lane changing. This results in turbulence, which in turn cause a slowing down of the forward movement of traffic and hence a loss of traffic throughput. Thus a small perturbation in the flow can be compounded into a major bottleneck in a matter of seconds, requiring rapid early engagement and intervention actions to prevent flow breakdown.

3.1.4.3 Control inputs required for freeway route optimisation

It was highlighted in Section 3.1.4.2 above that freeway capacity is not deterministic but rather probabilistic and with a significant range of variability. To optimise freeway performance with such variability in the objective target, it is necessary to:

- Understand the metrics of traffic flow optimisation under a range of conditions;

- Collect real time traffic data and manage the inevitable errors and noises in that data to provide an accurate and reliable real-time data source;
- Measure and adjust (smooth) the randomness of traffic demands across the network (i.e. every ramp and every lane in the managed route);
- Account for the myriad of individual driver behaviours in real time and their effects on traffic flow;
- Account for individual vehicle characteristics such as size, length, braking and acceleration rates that affect real-time operational capacity;
- Measure in real-time changes in speed, volume and density to enable real time optimisation tuning;
- Allow for the differences between each freeway section (e.g. 500 m length covered by a detection source) for historical critical values of density, speed and volume as well as differences in real-time objective targets for the same measures; and
- Use feedback control regulators in real time to dampen out strong oscillations in the traffic (data) to reach stable control values around the true control points.

A bottleneck may occur three to four kilometres downstream of an entry ramp, so three to six minutes travel time may elapse before a vehicle reaches the bottleneck location; this causes significant oscillation in the traffic data used for feedback control. Hence the need for early start-up settings to activate and maintain stability and prevent flow breakdown.

The long list of requirements highlights that the optimisation of the performance of a freeway route requires considerable real-time data collection, processing and analysis. Multiple bottlenecks can form on a freeway route, sometimes simultaneously, which requires a freeway optimisation control system that can deal with simultaneous optimisation of multiple bottlenecks on the one managed route.

3.1.4.4 Optimisation approach and using multiple optimisation algorithms

The objective target for the optimisation of Victorian freeways is to maintain stable traffic flow conditions to provide better reliability and travel times for road users as well as to maintain greater throughput (of people, goods and vehicles) compared to congested stop-start traffic. Maintaining greater throughput of people, goods and vehicles benefits road users and the community and on tolled sections also maximises toll revenues.

In urban freeway networks with closely spaced ramps and relatively high entering traffic volumes, the most effective control of the freeway performance is through managing entering traffic. In almost all such cases, coordinated ramp signal control such as HERO LIVE will be the primary optimisation algorithm. Other optimisation algorithms, such as dynamic speed limits, would need to act in support of the ramp signal algorithm to extend its effectiveness.

The operational basis for the HERO LIVE algorithm has been extended over time to deal with a greater number of situations; however, the fundamental principle remains to prevent traffic density from exceeding a critical density threshold and therefore avoid flow breakdown and inefficient, congested conditions.

Each freeway route will contain a number of potential bottlenecks and a number of controllable locations that can be used to manage the freeway, most notably the entry ramps. VicRoads' approach to optimising the freeway by maintaining traffic density below a critical density which considers both lane and carriageway conditions is through:

- Controlling the entry flow of the nearest entry ramp to a bottleneck;
 - ... and while doing so, manage the queues on the ramp to limit impacts to surface roads;
- Calling upon additional entry ramps to reduce traffic entering upstream of the bottleneck; and
- Using dynamic (variable) speed limits on the freeway to slow down traffic on the approach to the bottleneck and reduce the pressure on the bottleneck.

This third step of using dynamic speed limits to support the optimisation task is still a developing activity. Although variable speed management is used more extensively in Europe, the approach in Victoria has been adapted to ensure it supports the optimisation of the freeway through entry ramp control as most of these European dynamic speed limits operate in isolation. There is potential for ramp signal and dynamic speed limit algorithms to operate in conflict and provide worse outcomes than if only one had been used in isolation and therefore care must be taken to ensure that the algorithms complement each other rather than compete. As each dynamic ITS tool impacts the traffic flow outcomes in different ways it is essential that traffic engineers have a full understanding of the traffic science and physical mechanisms in operations and how these influence the real time fundamental diagrams. It is essential that all optimisation tools are all operating in concert with the combined objectives of improving road safety, efficiency and productivity (product of Speed and flow).

Reducing the speed on the freeway in advance (upstream) of the potential critical bottleneck creates a managed bottleneck by increasing the density of traffic. This managed bottleneck is used to avoid the emergence of flow breakdown at the critical bottleneck downstream as by doing so it is possible to improve overall throughput, reliability and travel times.

Dynamic speed limits can also be used to try and assist a freeway to recover from flow breakdown at a critical bottleneck should this occur, however further development is still required for this to function in partnership with the optimisation activities of the entry ramp control.

A freeway optimised through the approach outlined above can be expected to operate more safely, as the smoother traffic flow means less sudden deceleration events of the type most strongly linked to crashes.

In addition to multiple algorithms working together to achieve optimisation, the same algorithms need to co-exist with traffic management and control interventions. In Section 3.1.3 it was outlined that such interventions can include changes to lane status (open, closed, special use) as well as changes to speed limits such as for queue protection. In these cases there is generally an overriding need for this intervention to occur and any dynamic optimisation algorithms such as ramp signal control and variable speed limits need to be integrated in this changed environment for best outcomes.

3.1.4.5 Managing the interface to arterial roads

Although route optimisation of a freeway is primarily focussed on the optimisation of that freeway, this must always occur in a network context, including managing the interface to other freeways and arterial roads.

Minimising impacts to arterial roads and other freeways

Where possible, freeway optimisation activities should avoid any negative impacts on the performance of arterial roads. Impacts on these other roads are minimised through:

- Effective freeway optimisation by HERO LIVE algorithms, resulting in increased throughput on the freeway route and removing or reducing queues that would otherwise occur on ramps (i.e. better throughput on the freeway means more vehicles can enter from the ramps);
- Management of ramp queues by HERO LIVE algorithms, including queue control, queue override, waiting time and coordination between ramps; and
- The design of entry ramps to provide adequate ramp storage.

All of these approaches are covered in more detail in the VicRoads FRSH (2013c).

Coordinating management of freeways and arterial roads

In addition to minimising impacts between routes, managing the interfaces between the optimised freeway route and other freeways and arterial roads also involves coordinating the management of these different routes. Such coordination of management is particularly relevant during unusual conditions such as during incidents and events.

For route optimisation, coordination actions between different routes take the form of traffic management and control interventions. This means that coordination actions change operational regimes on routes to make them more complimentary. Each route is then optimised within this new optimisation regime, but without continuous fine-tuning towards an explicit network optimisation objective target.

Specific coordination approaches are addressed in more detail in Section 4 of this Framework.

3.1.4.6 Optimisation during works and incidents

Road works, incidents and events change and generally reduce the capacity of the road network, making the ability to optimise the use of the remaining capacity particularly important. These situations often involve lane closures and changes to speed limits. The changes are effectively traffic management and control interventions and it was noted in Section 3.1.4.4 that route optimisation approaches need to adapt to changes in the route environment and continue to optimise performance as best possible.

One challenge of maintaining route optimisation during road works is the reliance of optimisation on high quality data inputs for control, as outlined in Section 3.1.4.3. For major works, consideration should be given to securing alternative data sources if the normal data sources cannot be maintained. Some reduction in quality of data may be able to be tolerated in order to boost availability of data; however, the effect of any such trade-off should be carefully considered.

3.1.4.7 Route optimisation of arterial roads

This Framework focuses on the active management of Melbourne's motorway network and hence the focus of the discussion on route optimisation has been on freeway route optimisation. In the overall network context, arterial route optimisation is also important, but ultimately outside the scope of this Framework, which limits its focus in that regard to optimisation of the interface between motorway and arterial networks. Coordination between freeway and arterial roads is discussed mainly in relation to traffic management and control interventions.

3.1.5 Multi-modal network optimisation with journey management

VicRoads' SmartRoads approach explicitly recognises the growing complexities of managing a road network such as the importance of and need to cater for the variety of different on-road transport modes. On-road transport modes include walking and cycling and road-based public transport, as well as freight and general traffic.

The number of modes with different needs, the existence of the transport network within a complex urban environment, and the complexity of the transport network itself, all make the task of true multi-modal network optimisation a challenging one. In addition, as much as we can look to optimise a system for the best overall system outcome, transport is comprised of people moving around and we must work with and manage these individual journeys.

Road users understandably want travel experiences that best meet their needs, even though generally a system that provides optimised journeys for each user (i.e. user equilibrium) does not provide the absolute best community outcome (i.e. system equilibrium). The tension between user optimum and system optimum adds further complexity to setting objective targets for multi-modal network optimisation.

3.1.5.1 What might multi-modal network optimisation look like?

The first step in moving towards multi-modal network optimisation with journey management is to envision what this might look like in practice. The points below are guided by VicRoads' SmartRoads approach, VicRoads' current approach to road network management and experience from innovative European real-time operations:

- Travellers and operators can easily and seamlessly access all relevant multi-modal information sources in real-time;
- A Victorian Integrated Traffic Management Centre (ITMC) hosts road and public transport operators and other stakeholders such as the police to jointly develop and implement traffic management and incident response plans;
- An integrated Graphical User Interface for freeways and principal networks, covering both the Principal Traffic Flow Network (PTFN) and Principal Public Transport Network (PPTN), shows the current traffic state including parameters such as travel speed, traffic volumes/demand, spare capacity and operating gap at intersections;
- The real-time Operating Gap in particular locations (like intersections) and overall (sub-networks or entire network) is being tracked and aimed to be minimised to provide network optimisation;
- A range of automated and semi-automated traffic management and control intervention system tools assist ITMC operators and staff to operate a wider managed roads network;
- Tools such as a 'road works booking and management system' based on standardised (typical) demand patterns and capacity values assist in managing the impact of planned disruptions to the network; and
- Congestion on freeways and principal networks is being tracked, recorded, reported and addressed as part of continuous improvement and ongoing innovations to the management approach.

3.1.5.2 Multi-modal network optimisation life-cycle

Network optimisation occurs across a life-cycle (refer to Figure 3.1), starting with initial analysis and planning, then design and implementation, followed by real-time optimisation and operations, evaluation and continuous improvement which then leads back to analysis and planning for further improvements.

SmartRoads provides an important entry point to this life-cycle, providing clear direction to support that initial analysis and planning stage. VicRoads' SmartRoads Guidelines (2013b) identify that SmartRoads provides a structured framework involving all stakeholders, to enable decisions about all transport modes to be made in a way that ensures that they support the surrounding land use. In this way, the SmartRoads process assists network optimisation to align with the overall urban environment.

The active management of Melbourne's motorway network is a key contributor to a number of SmartRoads strategies, such as:

- SmartRoads Strategy 1.1: Encourage general traffic to use arterial roads that avoid significant conflicts with abutting land use;
- SmartRoads Strategy 4.2: Optimise the network capacity for all modes of transport and reduce journey times;

- SmartRoads Strategy 4.4: Provide priority on the Principal Freight Network and connections to freight activity centres;
- SmartRoads Strategy 4.7: Recognise traffic routes linking key destinations; and
- SmartRoads Strategy 4.8: Ensure that overall network efficiency for all modes is considered in real time.

In moving to the next stages of the optimisation life-cycle, design and implementation, it is appropriate to seek to draw upon and adapt the SmartRoads process. The SmartRoads level of service (LOS) measures are currently used frequently in planning stage assessments of infrastructure projects and reflect the need to cater for that purpose. In developing overall network objective targets, some of the Operating Gap measures in SmartRoads would require greater adaptation than others. Measures such as Pedestrian Level of Service C (Opportunities to cross within reasonable distance to key desire lines and moderate wait times) would require substantial modification to be able to be used in a real-time Operating Gap optimisation approach.

Optimisation approaches adjust system parameters in order to achieve a target value of an objective function. This approach can be seen clearly in the simplest form of ALINEA that started the development of HERO LIVE ramp signalling. In this simplest form of ALINEA, ramp signal timings are adjusted so that the occupancy (density of traffic) on the freeway mainline at the local entry ramp merge approaches the objective target (i.e. target occupancy value). In this example, the objective function is indirect as managing mainline occupancy is a means to achieving good freeway performance and is an indicator of freeway performance rather than a direct measure such as speed or travel time. In many traffic signal systems, the objective function is based around some measure of total delay, with a target value of minimising delay (zero) or some combination of delay and stops. Similarly, as part of its adaptive nature, SCATS adjusts intersection timings to balance the degree of saturation on all approaches and where possible maintain saturation below a threshold value.

In implementing network optimisation, it may be possible to use an overall network objective target derived from the SmartRoads Operating Gap approach. In doing so however, two important steps would need to be completed:

- Update the Operating Gap approach to ensure its appropriateness for use in real-time network automated optimisation; and
- Substantially expand ITS control system functionality and add the broader range of required inputs to be able to explicitly assess and optimise network objective targets.

These two activities above would require a significant investment to fully roll out, although this investment may be small in comparison to the cost of new or upgraded transport infrastructure. The high-level objective targets set out in SmartRoads merely indicate the desired state and not how to fine-tune operations to achieve it, so substantial work would need to go into establishing the finer level of control required to realise the desired performance. In many cases this finer level of optimisation is likely to be substantially similar to current route optimisation approaches with adaptation to support the explicit achievement of a network optimum.

3.1.5.3 Practical steps towards multi-model network optimisation

There is support for the principle of multi-modal network optimisation; however, it is clear from the discussion in Section 3.1.5.1 that it would not be a small undertaking to implement. It is therefore logical to consider practical steps that can be undertaken to work incrementally towards that vision. The following strategies are considered as traffic control and management interventions and route optimisation strategies but are starting to embody the principles of integrated network operation and optimisation.

Wide Area Network Dispersion (WAND) during incidents

One such practical step relates to how traffic management and control interventions are used during times of incidents to provide operational management responses closer to what network optimisation would achieve. During major incidents, the WAND strategy aims to unload the motorway traffic over a long distance in a structured way using traveller information services (i.e. mainline and arterial VMS and in-vehicle systems) as well as LUMS (if available). Dispersing traffic over a wide area upstream of the incident spreads the traffic over a number of arterial roads, rather than at a single exit just upstream of the incident. In a major event such as a tunnel or bridge closure the system would provide Melbourne-wide traveller information so that motorists can change routes to totally avoid the incident and the congestion on roads near to the closure.

Improved management of arterial road interfaces

Some potential exists within the existing control system arrangements to better manage arterial road interfaces using SCATS Action Lists called from within STREAMS. Currently it is easier to call Action Lists based on entry ramp queues and a logical extension to STREAMS would enable it to be used more easily for exit ramp queues as well. SCATS Action Lists are an extremely flexible tool as they can include most commands available within SCATS to modify arterial traffic signal operation. Developing useful Action Lists for a variety of situations at each freeway interchange is a substantial task and any developed Action Lists would require ongoing maintenance to ensure continued appropriateness to network conditions. Interacting with any potential future overarching Arterial Road Management System (conceptually referred to as ARMS) therefore offers the opportunity to substantially simplify management of arterial road interfaces as well as improve network performance and utilisation of alternate routes.

3.1.6 Desired level of active management

The models of the layers of active management shown in Sections 3.2 and 3.3 drew inspiration from the Capability Maturity Model (CMM) approach, adapted as appropriate and rotated 90 degrees from a normal CMM illustration. An important feature of the CMM approach is that more advanced is not always more appropriate or desirable. For example while the more advanced levels of active management achieve stronger outcomes they also bring significant cost and complexity.

The appropriate level of active management for any road network element must therefore be determined by need: how much active management is needed to achieve the required outcomes. As Melbourne continues to grow and demand growth continues to outstrip additions to transport infrastructure it is expected that the required levels of active management will continue to increase. Decisions on the appropriate level of active management should therefore indicate an appropriate planning horizon to ensure that the decisions of today provide for the required active management of the future.

The overall organisational level of active management will be determined by the most critical road network elements managed by that organisation, even where the majority of that network does not require that level of active management. Given the existence of multiple road operators in Melbourne's road network, consideration is also required as to the relative roles of each of these operators. Given the scope of network and route optimisation extending across boundaries, there is merit in considering whether these activities could be centralised to save complexity for individual operators, with those operators continuing to perform network intelligence, traveller information and on-road incident and traffic management and control interventions as appropriate. Any such approach would still need to meet all objectives of coordinated control and incorporate management across modes.

Regardless of whether optimisation activities are centralised or locally managed, for any routes or networks that are optimised, the requirements for network intelligence are driven by that higher level of active management for the full route or network.

It is important to note that the levels of active management reflect increasing complexity rather than relative priority. This distinction is most evident in the response to incidents where in the local area of the incident the traffic management control and intervention activities such as road and lane closures will take precedence and the optimisation functions will need to adapt to this changed environment.

3.2 Road network perspective of the levels of active management

Table 3.3 provides a model to illustrate the different levels of active management from a road network perspective. The horizontal rows represent the five layers of active management and the vertical columns represent five target states for active management. Each target state includes all boxes below and to the left of that point. For example the target state for a network of optimised routes means that a total of 10 cells are relevant – the four in that column and the six to the left.

3.3 Managed Motorways perspective of the levels of active management

Table 3.3 illustrated the levels of active management for the full road network; Table 3.4 focuses on the case of Managed Motorways.

Table 3.3 Levels of active management – a road network perspective

Target states:	Road operator understands performance	Travellers can make informed choices	Respond to changing conditions Keep the road open	A network of optimised routes	An optimised network
Multi-modal network optimisation and journey management					Simultaneous optimisation across network links and different user groups to achieve a 'one network' optimum that also optimises user journeys
Route optimisation control				Real-time, continuous fine tuning of traffic control settings to attempt to realise full potential capacity of route (adaptive control)	+ route optimisation objectives adjusted to support achievement of network optimum
Traffic management and control interventions			Intervene to change operations to better reflect needs, e.g. change open lanes, set special event signal timings, change speed to reflect works or incident risk environment	+ interventions are coordinated with optimisation activities so that they work together rather to support improved performance	+ interventions are tailored to assist achievement of network optimum
Traveller information		Provide transport users with travel times and incident information to support informed travel	+ support road users through contextual information on interventions (e.g. why lane closed, speed changed)	+ support demand management measures to assist balance between demand and supply for route optimisation	+ provide seamless intermodal journey information in a proactive and personalised manner
Network monitoring and intelligence	Identification of congested areas and periodic performance reports	+ travel times on key routes and some automated detection of incidents	+ near real-time performance data to support intervention decisions	+ fine level true real-time continuous flow of data for use in optimisation algorithms including status of intervention actions	+ full multi-modal performance data for all network links and details of transport user end-to-end journeys

Table 3.4 Levels of active management – a Managed Motorways perspective

Target states:	Road operator understands performance	Travellers can make informed choices	Respond to changing conditions Keep the road open	A network of optimised routes	An optimised network
Multi-modal network optimisation and journey management					Wide area network optimisation assesses network optimum and guides motorway route optimisation and coordination activities
Route optimisation control				Adaptive control of mainline density and speed to avoid and recover from flow breakdown through continuous adjustments to ramp signals and mainline speed limits along a corridor	+ objective functions for route optimisation adjusted in real-time for required network role; interchanges between freeway routes are fully managed
Traffic management and control interventions			Lane availability and speeds set periodically to meet requirements (e.g. open lane for peak demand, close lane and reduce speed for incidents)	+ Changed signal settings on surrounding arterial roads; changes to freeway lane availability and speed limits cooperate with adaptive control algorithms	+ response rules and plans make full use of available freeway and arterial network; a response on one route changes operations also on other routes
Traveller information		Freeway users provided with freeway conditions, travel times and incident information	+ Freeway users provided with supporting information for changes in lane availability and speed limits	+ Freeway users provided with real-time information about alternate routes prior to entering the freeway	+ to assist users navigate the large volume of available information, information is personalised for a user's journey and provided proactively
Network monitoring and intelligence	Collection of fundamental freeway data to analyse and understand traffic conditions	+ processing and calculation of freeway travel times, freeway conditions, identification of congested areas and performance reporting for near real-time use	+ near real-time detailed performance data to support intervention decisions presented on a graphical user interface	+ fine level real-time data on freeway, ramps and surrounding network as required by optimisation algorithms	+ real-time data available for other journey options, including alternate routes and modes

3.4 The active management layers and active management tools

The layers of active management indicate broadly how a road operator wishes to manage its network and the complexity that entails. The next step is to examine the methods for available for doing this, being the management approaches available to optimise, to intervene and to inform. These management approaches form part of the Managed Motorways toolkit and are examined in Section 4.

Section 4

Summary – The Managed Motorways toolkit

The Managed Motorway toolkit consists of a variety of tool chains that assist managing traffic entering the motorway, traffic on the motorway and traffic exiting the motorway.

These tools include:

- Control tools – There are two types of control tools. The first is responsible for intervening to control traffic speed and lane/carriageway use following an incident, congestion or other event. For example, integrated speed and lane use management systems (LUMS) and entry ramp management systems that support freeway closures. The second type of control tools are for route and network optimisation and these include coordinated ramp signals (CRS), dynamic variable speed limits (DVSL), arterial road interface and exit ramp management systems.
- Information tools – These tools provide real-time information to road users via on-road variable message signs (VMS) as well as through publication of data to third parties for wider dissemination via mobile phone and in-vehicle systems. Provision of information on travel times and freeway conditions on both the arterial and motorway network can assist in managing demand across the network, particularly during incidents and congestion.
- Intelligence tools – These tools provide the real-time data that is critical to identifying and monitoring network performance issues and providing the inputs to dynamic algorithms that fine-tune towards a defined objective target.

A set of guiding operational policies that govern application of the Managed Motorways toolkit is provided in this section, followed by a more detailed description of each component within each tool chain, including high-level functional and technical requirements and specific operational policies for each tool.

The Managed Motorways toolkit together provides an integrated system for management of traffic and has critical dependencies between different components and across tool chains.

This is particularly the case for optimisation tools, which must be fully managed, regardless of whether there are located on multiple road operator sections, as a single coordinated system using the Traffic Operating Software of the State (TOSS). Optimisation tools are only as good as the inputs that go into them, and unless data and information is shared in real-time through the system and a route or network-level coordinated response is possible, the full system benefits will not be realised. This is particularly the case for CRS, which requires all system inputs to be controlled in order to be able to manage multiple simultaneous bottlenecks on the mainline and in a fair and equitable manner.

The detailed reasoning behind the requirement for a Traffic Operating Software of the State (TOSS) is provided, with reference to Section 7 for more detailed performance requirements relating to a system-to-system interface.



4. The Managed Motorways toolkit

The Managed Motorways toolkit includes various technologies and control strategies for delivering different levels of active management. This section firstly provides an overview of the toolkit in its entirety before providing the high-level functional and technical requirements for each tool, in line with the Systems Engineering methodology. More detailed performance requirements are provided in Section 7.

4.1 Overview

The individual tools available for use in the active management of motorways are listed in Table 4.1, including tools that are currently in operation as well as tools that are in development or planned for development. Each Managed Motorways tool is part of a total system.

Table 4.1 The Managed Motorways toolkit

Control Tools		Foundation Tools	
Optimisation Control	Intervention Control	Information	Intelligence
Coordinated ramp signals (CRS) system	Lane use management system (LUMS) including variable speed limits (VSL)	Variable message signs (VMS)	Traffic detectors (primarily speed, volume and occupancy – SVO – data)
Dynamic variable speed limits (DVSL) ¹	Entry ramp management system	External information publication for third party use	CCTV
Arterial road interface system	Wide area network dispersion (WAND) ²		Automatic incident detection (AID) ²
Arterial road management system ²	Motorway dynamic re-configuration (including entry and exit ramp mgt systems) ²		Congestion alarms ²
Exit ramp management system ²			Real-time graphical user interface (GUI)
End-of-motorway management system ²			Weather and environmental monitoring system

¹ Tools currently in development

² Tools planned for development

As illustrated in Table 4.1, control tools can be separated into two categories depending on their primary function in relation to the levels of active management (i.e. Optimisation or intervention). Some control tools will use the same field devices; for example the coordinated ramp signals (CRS) system and the entry ramp closure management system both utilise traffic signals to control traffic on the entry ramp.

Intelligence and Information tools are considered as foundation tools and are applied to all motorways and arterial roads approaching the motorways in Melbourne. They contribute to all levels of active management and provide critical support to the control tools as well as delivering other functions for real-time operations and business intelligence through network and system performance evaluation.

The real-time GUI is a critical component to provide operators with easy-to-access information on device status and the operational performance of the motorway mainline, ramps and connecting surface road network (arterial and other lower order roads - refer Section 1.4). Further detail regarding the GUI is provided in Section 5.1.

Other foundation infrastructure includes the control software, power infrastructure and ICT hardware and networks (in the field and at VicRoads offices) required to operate the ITS tools.

Table 4.2 summarises how each tool contributes to the different levels of active management; the key is as follows:

- 'P' is used if it is the primary function of the tool to deliver that level of active management
- 'S' is used if it is a secondary function of the tool to deliver that level of active management
- 'Su' is used if a tool supports other tools in delivering the required functionality for that level of active management
- '-' is used if the tool does not contribute to a particular level of active management.

It can be seen from Table 4.2 that there is only currently one tool whose primary function is multi-modal network optimisation; this reflects the emerging nature of this level of active management and likely in the longer-term more tools will be developed to deliver this function.

Table 4.2: Contribution of Managed Motorway tools to different levels of active management

Managed Motorways Tool		Level of Active Management				
		Network monitoring & intelligence	Traveller information	Traffic management & control interventions	Route optimisation	Multi-modal network optimisation with journey management
Optimisation Control	CRS			S	P	Su
	DVSL			S	P	Su
	Exit ramp mgt.			S	P	Su
	End-of-motorway mgt			S	P	Su
	Arterial road interface mgt			S	P	Su
	Arterial road mgt system (ARMS)			S	S	P
Intervention Control	LUMS (including VSL)			P	Su	Su
	Entry ramp mgt			P	Su	Su
	WAND			P	Su	Su
	Mwy dynamic re-configuration (incl entry/ exit ramp mgt)			P	Su	Su
Foundation	VMS		P	Su	Su	Su
	Publish to third parties		P	Su	Su	Su
	AID	P	Su	Su	Su	Su
	Traffic detectors	P	Su	Su	Su	Su
	CCTV	P	Su	Su	Su	Su
	Congestion alarms	P	Su	Su	Su	Su
	Weather and environmental monitoring	P	Su	Su	Su	Su
	Real-time GUI	P	Su	Su	Su	Su

This Framework has already highlighted the importance of the tools working together to deliver active management outcomes. Section 4.2 outlines the common high-level operational principles governing the use of Managed Motorways tools and in particular the implementation of control actions.

When considering how the tools work together, and for design purposes, it is useful to think about the specific tool chains (or sub-systems) working to manage different parts of the traffic stream as it interfaces with and uses the motorway network.

These tool chains can be categorised as follows:

- Those that manage traffic entering the motorway
- Those that manage traffic on the motorway mainline
- Those that manage traffic exiting the motorway.

Within each tool chain, there are important interfaces and dependencies that affect the functionality of each tool as well as design considerations such as layout of devices and system performance requirements.

Sections 4.3 to 4.5 provide information on the operational policies and critical high-level functional and technical requirements for each of the tool chains. As outlined in Section 1, these requirements are considered critical within this Framework as they directly support the way in which the Managed Motorways tools must operate and be optimised to achieve the desired performance outcomes. They are not the complete set of functional and technical requirements for CRS as requirements also exist for other reasons. Note that details regarding the GUI are provided in Section 5.

More detailed technical requirements (suitable for inclusion in specification documents) are provided in Section 7 of this document, based on the system performance criteria identified in Section 6.

Each tool is subject to certain criteria, or warrants, as to where it is required on the network, and to what level of provision. For example, motorways with high traffic volumes and peak hour flows are more likely to require installation of control tools, as well as reduced spacing of foundation tools such as CCTV and detectors. Not all locations may necessitate full coverage of all tools in the immediate future; however, Managed Motorways design should allow for

future upgrading of the motorway network to fully managed operations once demand is at sufficient levels. The criteria for provision of each tool are outlined in the VicRoads Managed Freeways Policy (2013a).

A high standard of design is required for safe and efficient operations. For example, coordinated ramp signalling operation requires adequate design for capacity and storage at the entry ramps so that during operations the discharge rate and queue length can be managed within the required thresholds. If adequate ramp storage is not available, then surface road approaches may also have to be used for storage.

It is also important that the design intent and assumptions are clearly understood by operators so that the operational practices are supportive to the principles on which the project was developed. If it is determined that the design cannot be made to accommodate demand due to physical restrictions or other constraints, then coordinated ramp signalling must be applied to manage the demand within capacity. A multi-disciplined approach is generally needed to optimise network outcomes.

This Framework does not provide detailed information regarding best practice geometric and ITS design of Managed Motorways projects. For more detailed guidelines on design refer to:

- VicRoads Managed Freeway Guidelines (MFG) (2014) (future function of guidelines to be confirmed)
- VicRoads Managed Freeway: Freeway Ramp Signals Handbook (FRSH) (2013c)
- VicRoads Managed Freeway Handbook for LUMS, VSL and Traveller Information (MFH) (2013d).

4.2 General operational principles for control

Operation of the Managed Motorways system and implementation of control actions through optimisation and intervention control tools is guided by the following key principles:

- The strategic operation of a motorway network may deem some sections of motorway network as being of higher importance. This may include tunnels, sections with alternative routes, linking sections, or sections designated for strategic priority for users (e.g. public transport to central areas or other strategic locations such as airports, and freight corridors to major ports etc.). These motorway sections may require management at higher priority to others as appropriate at certain times of day, in accordance with SmartRoads principles.
- The economic imperative to make the best use of the total road network means that, when necessary, the motorway network is to be given priority over the surface road network (arterial and other lower order roads - refer Section 1.4) and, where this would result in a negative impact on the surface road network, this should be managed accordingly to provide a net overall gain to road users. Section 2 illustrates the productivity benefits derived by keeping Victoria's highest value road asset (the motorway network) flowing and operating at its highest operating capacity during congested periods. Management of the surface road interface is also critical to ensure efficient supply and discharge from the motorway both under normal day-to-day and incident operations.
- VicRoads will generally not implement a control action (i.e. intervene in the operation of a motorway) unless an existing or potential traffic or safety problem is evident. Typically this means there will be no control applied when all sections of the motorway are operating below the capacity required for stable flow and no incident or road works event is active. Control actions will be implemented:
 - when the volumes on a motorway is exceeding or is likely to exceed the conditions for stable flow;
 - to avoid a potential safety problem occurring;
 - to prevent an existing problem from escalating into a bigger route or network problem;
 - to prevent vehicles being trapped in the freeway section for long periods following a major incident;
 - to restore the motorway network to its full capacity and safety;
 - to manage motorway to motorway connections and/or
 - to manage the motorway/surface road interface such that the road operations actively support and do not negatively impact on motorway operation or safety.
- Control actions should be applied to manage problems at the local level in the first instance. When the ability for local control to manage the problem is exceeded, control is progressively escalated to a wider response that should be implemented on the basis of fair and equitable access to use of the motorway network, and only at points where control of traffic at the location will contribute to addressing the problem.
- Control actions will generally involve a range of ITS tools acting together rather than a single tool operating alone e.g. traveller information will support CRS and LUMS interventions during an incident by encouraging early diversion from the affected motorway.
- If flow breakdown does occur or incidents escalate or are likely to escalate, then more aggressive priority measures may be deployed to assist with flow recovery and should be implemented as early as possible to stop the problem from propagating more widely across the network.

- The management of the motorway network as a system needs to allow in the future for the possibility of dynamic re-configuration in order to continue to maximise the utility of the network for Melbourne’s motorists. This will enable real-time operations to evolve with longer-term changes in traffic patterns that may mean the freeway configuration in the original design is no longer optimal for all times of the day.

Dynamic re-configuration may include severely restricting or even physically closing and opening entry and exit ramps and/or mainline lanes to enable increased throughput on the mainline. Such measures would generally be implemented at peak periods, for example: operating an entry ramp with added lanes and a merge as add lane only; closing ramps with lower volume entries that are contributing to flow breakdown on the mainline; and closing freeway lanes to allow high flow entry ramps to join as added lanes rather than merges. Benefits could also be achieved during other periods, such as closing lanes at night to enable increased speed limits. Robust monitoring and evaluation is required to support future development and operation of this strategy.

To get the best outcomes from the Victorian motorway network, operational decisions will need to be made at the network level. Although the motorway network comprises many interconnected freeway routes it has sections that may be operated by different road operators. VicRoads approach to Managed Motorways operations requires the motorway network to be managed as a single system with Managed Motorways tools and supporting systems to provide seamless and consistent operation along routes and between connecting freeways regardless of operational boundaries.

Future road pricing and tolling regimes including toll caps have the ability to significantly skew traffic patterns and create toll avoidance points, often causing localised network bottlenecks on the freeway and arterial road network (as can be seen at Toorak Rd, Power St, and Bell St and Springvale Rd). Therefore, motorway pricing decisions are also operational decisions and must consider outcomes at the network level.

4.3 Managing traffic entering the motorway

The primary control tool for managing traffic entering the motorway is coordinated ramp signals (CRS), which manages the flow of traffic from entry ramps in order to prevent flow breakdown on the motorway mainline. CRS is an optimisation control tool since it involves continuous fine-tuning of algorithms to maintain stable traffic flow on the mainline.

Intervention control tools are also used to manage entering traffic; these include:

- Entry ramp management system, which utilises the same traffic lights on entry ramps but deploys different control strategies to the CRS system to severely restrict or prevent access to the mainline when there is an incident or congestion; and
- Arterial road management systems (including SCATS), which interfaces with CRS and the entry ramp management system to manage demand to the entry ramp and optimise use of cycle time for other movements at the arterial intersection.

The control tools for managing traffic entering the motorway are supported by the following chain of foundation tools:

- Variable message signs, which assist with demand management during congested periods;
- Traffic detectors, which provide data and control points for the control algorithms; and
- CCTV, which provides visual monitoring of CRS and arterial road operations.

VSL signs must also be provided on entry ramps for motorway sections with LUMS (see Section 4.4.1 for detail on functional and technical requirements).

The system must be integrated with the following control tools installed on the mainline (see Section 0):

- LUMS, which affects operating capacity of the mainline in real-time; and
- DVSL, which assists CRS in managing mainline capacity and bottlenecks, and safety at back of queues.

The following sections provide operational policies (for control tools only) and critical high-level functional and technical requirements for each tool that contributes to managing traffic entering the motorway.

4.3.1 Coordinated ramp signals

The coordinated ramp signalling (CRS) system uses a dynamic algorithm to control motorway access at all entry ramps within the motorway system in order to manage the mainline flow to within the systems’ operational capacity. Traffic lights installed on entry ramps are used to meter traffic into the motorway in a measured and regulated manner. The objective of controlling motorway entry flows is to manage the mainline traffic volumes to near the critical occupancy (density) and prevent or delay the occurrence of flow breakdown and onset of congestion.

As described in Section 3.1.4, the operational capacity of a motorway is constantly changing and therefore the CRS system must be able to measure changes in motorway capacity and respond dynamically by altering the entry ramp metering rates. A coordinated system is implemented to allow use of multiple entry ramps to manage a mainline bottleneck and thereby maximise use of available ramp storage to provide more fair and equitable access to the motorway system.

VicRoads uses (and has a licence for the IP of) the HERO LIVE CRS system, developed by Professor Markos Papageorgiou from Technical University of Crete. HERO LIVE represents a substantial evolution from the original HERO system (developed by the same professor) and incorporates additional operational and control logic, statistical and estimation functions and feedback control regulators required for VicRoads' operational needs.

4.3.1.1 High-level functional requirements

The CRS system must control the exit flows from all motorway entry ramps as required on a 24/7 basis in order to:

- Keep mainline flows within critical occupancy (density), within the constraints of the available ramp storage;
- Manage multiple bottlenecks occurring at any location on the motorway;
- Assist with recovery of flow to stable conditions if breakdown does occur;
- Respond automatically to traffic conditions caused by incidents to reduce traffic entering the mainline during incidents (noting that this is expanded upon by other entry ramp management functionality); and
- Give priority access to high priority vehicles, where appropriate.

4.3.1.2 Operational policy

As traffic demand increases, the policy for control optimisation is as follows:

- Operate motorway-to-motorway ramps signals with lower delays (e.g. wait-time) than entry ramps from surface roads (arterial and other lower order roads - refer Section 1.4); then
- Avoid queues at motorway-to-motorway ramps from extending back to interfere with traffic on motorway through lanes or other movement within the interchange; then
- Minimise ramp queues extending back to interfere with through traffic on the surface roads; then
- Manage entry ramps to prevent flow breakdown on the mainline as priority over the extent of queuing on the controlled entry ramps. In the case of surface road ramps, queuing into an exclusive turning lane or into one lane of a three lane carriageway is generally acceptable.

If flow breakdown occurs and motorway-to-motorway ramps queues are becoming excessive with longer travel times being detected, or there is other excessive queuing within the motorway system, the policy for increased control intervention is as follows:

- Further reduce inflows from upstream surface roads entry ramps (including where needed, from ramps on adjacent upstream motorways); then
- Further reduce inflows from downstream surface roads entry ramps associated with the relevant bottleneck (i.e. there are surface roads entry ramps between the motorway-to-motorway ramp and the bottleneck); then
- Further reduce inflows from upstream motorway-to-motorway ramps.

Beyond this point, the entry ramp management system would act to severely restrict ramp entry flows and/or close entry ramps.

In the future, DVSL may also be integrated with CRS operations to provide support to CRS in managing mainline density on approach to a bottleneck and managing flow recovery after breakdown. DVSL would likely be implemented after CRS operations were in place, although the optimal strategies need to be determined through further development and operational testing.

4.3.1.3 High-level technical requirements

Table 4.3 sets out critical high-level technical requirements for the CRS system. As outlined previously, these requirements are critical requirements for CRS as they directly relate to the way in which the operational policy is to be achieved, however they do not represent all of the requirements for CRS. The same comment applies to the subsequent sub-sections covering high-level technical requirements.

Note that as VicRoads is utilising a corridor management approach to ramp signalling based on the coordinated strategy HERO LIVE, the requirements relating to local ramp metering algorithm ALINEA are not detailed in Table 4.3.

Table 4.3 High-level technical requirements for CRS

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.3.1.1	All motorway entry ramps including motorway –to- motorway ramps must be metered for effective control (i.e. no uncontrolled entries). Includes installation of ramp signals and supporting infrastructure (including VMS on surface roads and entry ramps – RC1, RC2 and RC3 signs).	Refer to FRSH Section 4.1.3 and 6.4, and MFG Section 3.7 for route-based ramp signalling treatments
4.3.1.2	On entry ramps where priority vehicle access is required, priority lanes are provided which can have a different metering rate than non-priority lanes on the entry ramps. All entry ramp priority lanes must be metered for effective CRS control.	Refer to FRSH Section 6.4.3 – note that VicRoads now supports use of metered priority lanes only (6.4.3.2)
4.3.1.3	Ramp signals activate and deactivate automatically when warranted by motorway conditions without operator intervention. Ramps will only switch on when the stable capacity is exceeded based on pre-set occupancy/speed thresholds (i.e. when there is unacceptable risk of flow breakdown as demand approaches operational capacity). Controls must be in place to prevent activation/deactivation when undesired. Safe start-up and close-down sequences are implemented using ramp signals and RC1 and RC2 signs.	Refer to FRSH Section 3.4.4, 7.3.1, 7.4 & 7.6.2.1 for dynamic activation/deactivation
4.3.1.4	CRS algorithms determine the critical occupancy (density) in real time at every bank of mainline detectors and use this information to determine the appropriate control points (target occupancies) and ramp cycle lengths. Calculations must be updated in a timely manner as required for the system to respond to changes due to vehicle mix and traffic conditions, including capacity changes as a result of speed changes and lane closures.	Refer FRSH Section 3.6 and 7.6.2.3 for control strategies and algorithms
4.3.1.5	CRS algorithms estimate the queue length and waiting time at each ramp based on measurements of flow from detectors at the ramp exit and entry, and occupancy from mid-ramp detectors. Metering rates (the exit ramp flows) are adjusted at each ramp to minimise the risk of queue overspill and prevent ramp storage being exceeded. If queue overspill occurs, then a pre-specified ramp exit flow is activated to reduce the queue length whilst avoiding an excessive exit flow that may trigger flow breakdown.	Refer to FRSH Section 7.6.2.4 to 7.6.2.6 on CRS queue estimation, queue control & queue override modules
4.3.1.6	HERO LIVE algorithm recruits multiple ramps as required to manage bottlenecks and balance queues and waiting times across entry ramps. HERO LIVE will first recruit the nearest upstream ramp to the bottleneck and then successive upstream ramps will be progressively recruited, providing they have sufficient traffic demand to assist in control of the bottleneck. Metering rates and queues of individual ramps must be determined according to the operational principles that apply during increasing traffic demand (refer to Section 4.3.1.2).	Refer to FRSH Sections 3.4.2 and 7.6.2.7 for HERO LIVE CRS operation
4.3.1.7	If longer travel times are detected as a result of flow breakdown and congestion on the mainline, HERO LIVE algorithms reduce entry ramp metering rates. As ramp queues increase and queue override modules activate, strategies may be deployed outside of HERO LIVE operation to continue to restrict entry ramp flows to lower values (i.e. override CRS to allow longer cycle times). Metering rates and queues of individual ramps must be determined according to the operational policies that apply during flow breakdown scenarios (refer to Section 4.3.1.2).	Refer to FRSH Sections 2.3.3 and 7.7 and Appendix D on recovery from flow breakdown
4.3.1.8	CRS calculations and implementation of control response in the field occurs with minimal delay and latency to ensure that the response is appropriate for current network conditions.	Refer to Section 3.1.4 of this Framework for further justification and Section 7 for detailed performance requirements
4.3.1.9	System can be manually tuned during operations when field devices are faulty or to reflect changes to traffic patterns that vary by day, by time of year (seasonally) and changes due to traffic growth generally. This includes tuning of both historical trends (setting ranges) and real-time absolute values.	N/A (to be developed)
4.3.1.10	System defaults to fixed time operations in the event of major technical faults. Fixed time operations will operate on the basis of a representative metering rate for the corresponding time of day/day of week.	Refer to FRSH Sections 3.4.3 and 3.4.4 on default fixed time operations
4.3.1.11	TMC operators are able to remotely override automated ramp signal timings. For example, to turn off ramp signals to clear queues for emergency vehicle access and to remotely close entry ramps during motorway closures (if not automatically activated via the entry ramp management system, refer to Section 4.3.2).	Refer to MFH Section 2.8 and FRSH Sections 7.7, 7.8.3 and 7.8.4 for ramp signals integration with other motorway operations during congested conditions and motorway closures
4.3.1.12	CRS system is integrated with automated incident detection systems, so that it is informed of the occurrence of an incident and reduces the ramp metering rate accordingly.	N/A (to be developed)

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.3.1.13	CRS system is integrated with LUMS and DVSL systems, so that it is informed of any lane closures or changes to the current speed limit and can adjust capacity/occupancy calculations and metering rates accordingly. This also ensures that the CRS is not falsely activated by a capacity or speed limit lower than the default values (since activation is based on pre-set values).	Refer to MFH Section 2.8 and FRSH Sections 7.8.1 and 7.8.2 for ramp signals integration with other motorway operations
4.3.1.15	Ability of CRS to manage a network of motorways by controlling ramps on separate adjoining motorways to deliver smooth control motorway to motorway merges, and at motorway-to-motorway diverges to effectively control for downstream conditions on both diverging legs.	Refer to FRSH Section 4.4 on motorway-to-motorway ramps. Full details of operation not available due to operational settings within HERO algorithm and STREAMS architecture

Additional background information on CRS control strategies is provided in FRSH Section 3.

4.3.1.4 Potential future developments

At the time of writing, the following functionalities are also being considered as part of the future development of the CRS system and should be considered in Managed Motorways design and operation:

- Ability to switch each ramp on using multiple detector bank locations;
- Improved HERO LIVE coordination strategies;
- Layering of control using bottlenecks further downstream rather than just immediately downstream for control;
- Ability to detect bottlenecks at the lane level to enable early control;
- Ability to dynamically interpolate conditions between mainline detector banks;
- Extension to HERO LIVE algorithms to optimise motorways seamlessly at the network level;
- Updated criteria for deactivation of coordinated ramp signals to include residual ramp queue lengths in addition to mainline capacity to avoid unintended flushing of ramp queues;
- Improved integration between DVSL and CRS so that DVSL can support CRS in managing mainline capacity on approach to a bottleneck through a mainline metering strategy as well as assisting CRS in recovering traffic flow after breakdown has occurred.

4.3.2 Entry ramp management system

This tool is still in development in order to enable a fully coordinated response between the motorway mainline, ramp and surface road control when either significantly reduced inflows or ramp closure(s) are required. The closure of ramps is a control intervention tool used in response to a major incident or severe congestion on the motorway mainline. The significant reduction of inflows is also a control intervention intended for wider use than ramp closures, for example when there is severe congestion but a full ramp closure is not warranted.

In the future, entry ramp management may work in conjunction with a dynamic lane management system that implements lane closures on low volumes ramps in response to increasing traffic flows on the mainline, so as to reduce turbulence on the mainline as a result of merging traffic (refer to Section 4.2 for further discussion).

4.3.2.1 High-level functional requirements

The entry ramp management system must intervene to reduce ramp inflows to minimum or near minimum levels as required on a 24/7 basis to:

- Assist management of severe congestion on the motorway, regardless of whether an incident is active;
- Assist faster recovery from severe congestion to smooth, productive flow; and
- Reduce the number of slow moving vehicles on the motorway to allow for easier management of any current or potential incidents.

The system must also manage safe closure of an entry ramp as required in response to a major incident or congestion so that:

- Vehicles are not trapped on the ramp or motorway;
- There is fast and safe access for emergency vehicles; and
- Additional traffic is prevented from entering the ramp (as enabled by arterial road management and entry ramp/surface road VMS, refer to Sections 4.3.3 and 4.3.4).

4.3.2.2 Operational policy

The entry ramp management system must take consideration of road based public transport and would generally operate according to the following operational policy:

- Entry ramp inflows will be significantly restricted during times of severe motorway congestion, regardless of whether an incident is currently active on the motorway. Within the management of the network, the management of the motorway is prioritised to maximise benefits to the greatest number of road users. Therefore, when this intervention is active, the management of the motorway takes priority within the network and normal ramp queue management approaches that would act to increase the ramp flow (to minimise queue overflow to the surface road) are suspended (refer to Section 4.3.1). Nevertheless, to reduce adverse effects, the entry ramp inflows will first be restricted at ramps that have the least impact on priority modes and major traffic flows.
- Entry ramp closures will be implemented as part of the operational response to managing major incidents or severe congestion on the mainline. It will generally be used reactively, however in the future may be implemented proactively on low volumes ramps in response to increasing traffic flows on the mainline, so as to reduce turbulence on the mainline as a result of merging traffic (as part of a dynamic lane management system, refer to Section 4.2).
- If an automated closure is not activated as part of the LUMS and motorway management system, then operators may manually identify the need to override HERO LIVE algorithms and implement a strategy to significantly reduce inflows at one or more ramp upstream of the affected motorway section.
- Entry ramp closures may also be manually implemented for a short time to flush the ramp of vehicles and allow emergency vehicle access (if the ramp has not already been closed as part of an automatic system response). In these scenarios, the operator should assess whether to manually keep the entry ramp closed to assist with incident management or whether automatic system control should resume and determine the optimal operational response for mainline traffic management.
- Entry ramp closures can be implemented via the following approaches:
 - Closing the ramp using the surface road traffic control system (SCATS), which will mean that phases for movements onto the entry ramp are skipped (and then re-introduced) as required (refer to Section 4.3.3).
 - Confirming the ramp is closed in STREAMS, which initiates a ramp signal close-down sequence to flush out existing traffic from the entry ramp, and then display appropriate messages on the entry ramp VMS (RC1 and RC2) and surface road VMS to prevent further traffic entering.
- When the mainline problem is mitigated and it is determined (automatically by the system or manually by operators) that the entry ramp can be re-opened, default operations will resume and entry ramp/surface road VMS should be used to advise motorists that the ramp is re-opened.

4.3.2.3 High-level technical requirements

Table 4.4 sets out critical high-level technical requirements for the entry ramp management system. Note that technical requirements are still in development for this tool and as a result this list is not yet complete.

No additional roadside infrastructure is required for the entry ramp management system above that already installed for CRS.

Table 4.4 High-level technical requirements for entry ramp management

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.3.2.1	Suspend CRS queue management on entry ramps on a configurable and prioritised basis to respond to identified severe congestion on a route	Refer to FRSH Appendix D.
4.3.2.2	Ramp closure operation is automatically or manually activated/deactivated as part of an integrated LUMS response within the motorway control system. When deactivated (i.e. ramp reopened to traffic), then default ramp operations will resume, which subject to traffic conditions mean that ramp signals may or may not switch on.	Refer to MFH Sections 2.8.1 and 2.8.3.
4.3.2.3	When ramp closure operation is activated, it overrides the HERO LIVE algorithms with the appropriate ramp closure sequence. When ramp closure is deactivated (i.e. ramp reopened to traffic), then default ramp operations will resume; ramp signals may or may not activate as activation is dependent on prevailing traffic conditions.	Refer to FRSH Sections 7.7, 7.8.3 and 7.8.4 and Appendix D, and MFH Section 2.8.3 and 2.8.4
4.3.2.4	Management of ramp closures and demand is supported by the arterial road interface management system and entry ramp/surface road VMS.	Refer to Sections 4.3.3 and 4.3.4 of this Framework

4.3.3.4 Potential future developments

In the future, entry ramp management systems may be used as part of the dynamic re-configuration of the motorway system to open/close ramps based on the need to manage demand to the motorway system and prevent the occurrence of flow breakdown or manage resulting congestion (refer to Section 4.2 for further detail).

4.3.3 Arterial road interface management

Arterial road interface management enables fully integrated control between arterial/surface road and motorway control systems at the interface with motorway entry ramps. This tool will be further developed as part of a wider Arterial Road Management System.

There are likely to be two phases to the development of arterial road interface management:

- **First phase:** use control interventions to adjust traffic signal settings to maximise network performance in response to ramp queues and/or closures;
- **Second phase:** as part of an Arterial Road Management System (ARMS), manage arterial/surface road intersections and links near the motorway to support motorway route optimisation within overall network optimisation.

This first phase is an evolution of current approaches whereas the network-level of optimisation in the Arterial Road Management System in the second phase represents a substantial change in managing Melbourne's road network. The requirements in this document reflect primarily this first phase of development and further consideration will need to be given to motorway interface requirements as part of the development of the Arterial Road Management System.

4.3.3.1 High-level functional requirements

The arterial road interface management system must adjust traffic signal control on the arterial/surface road approaches to the entry ramp as required on a 24/7 basis to:

- Support CRS operation (refer to Section 4.3.1) by managing demand to the entry ramps and keeping entry ramp queues within the available ramp storage during periods of high demand;
- Support management of ramp closures by preventing vehicles from accessing entry ramps during the closure and enabling traffic diversion to other routes (refer to Section 4.3.2);
- Maximise productive use of green time for arterial/surface road traffic movements when the motorway is congested and/or closed; and
- Provide rapid emergency vehicle access to the motorway when there is an incident on the mainline.

4.3.3.2 Operational policy

The arterial road interface system must take consideration of road based public transport and would generally operate according to the following operational policy:

- If CRS is active and entry ramp queues are increasing and threatening to overspill onto the surface road network, the arterial road interface system must proactively implement adjustments to signal operations at the arterial/surface road intersection to help manage demand to the entry ramp and queue overspill.
- Signal adjustments can be progressively implemented with increased severity based on the extent of ramp queues i.e. gradually taper the supply of vehicles entering the ramps. This may progress to no green signal for entry ramp movements if a full ramp closure is implemented. Green time should be reallocated to other surface road movements that can benefit from additional phase time.
- Alteration of phasing of adjoining signalised intersections may also be required to ensure that signal coordination is maintained.
- When entry ramp queues are on the decrease and CRS can manage ramp queues alone, then the arterial traffic control should return to default operations.

4.3.3.3 High-level technical requirements

Table 4.5 sets out critical high-level technical requirements for the arterial road interface system in relation to management of traffic entering the motorway. Note that technical requirements are still in development for this tool and as a result this list is not yet complete.

No additional roadside infrastructure is required for the entry ramp management system above that already installed for CRS or for arterial road traffic control (at the signalised intersection).

Table 4.5 High-level technical requirements for arterial road management approaching motorway entry ramps

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.3.3.1	Integrate SCATS and CRS systems, so that SCATS knows when adjustments are required on the basis of queue lengths (relative to ramp length) and ramp closures.	Refer to FRSH Section 8.2 and Sections 3.1.4.5 and 3.1.5.2 of this Framework for arterial road management at entry ramps
4.3.3.2	Implement SCATS trims that adjust signal phases for traffic entering the motorway e.g. modify right turn phase times, ban right turns movement, restrict left turn overlap times etc.	As above

4.3.3.4 Potential future developments

At the time of writing, the following functionalities are also being considered as part of the future development of the arterial road interface system and should be considered in Managed Motorways design and operation:

- Modification of phase times at connecting arterial/surface road intersections to manage demand to the motorway interchange (and provide for traffic diversions);
- Increased implementation of SCATS adjustments/trims through Action Lists to provide flexible, customisable control; and
- Improved integration of SCATS and CRS to allow for more consistent actions between sites that also do not require the manual methods of Action List creation and maintenance, providing for simpler control in addition to the flexibility of Action Lists.

The need for development of a wider arterial road management system that is integrated with motorway operations is covered in Section 4.6.

4.3.4 Variable message signs (VMS) including ramp control signs

Variable message signs are core components of an on-road traveller information system. They are installed on surface road approaches to motorways as well as on entry ramps to assist with management of demand onto the freeway network and to support safe operation of the CRS and entry ramp management systems.

VMS are increasingly installed on surface roads further away from the motorway where alternative routes are available, so that provision of travel time and motorway condition information can influence route choice. Positioning of surface road VMS should be considered as part of a network-wide traveller information strategy that considers motorway and arterial road management systems.

VicRoads current policy is to utilise multi-functional VMS that can display different message types for normal conditions (travel time information) and during incidents, congestion or planned events, as required.

The control hierarchy for display of messages on VMS is described in the MFH Section 4, with guidance on appropriate pictograms and message text provided in MFH Appendix B.

4.3.4.1 High-level functional requirements

VMS must provide reliable, real-time information on travel times and motorway travel conditions/closures to motorists on surface road approaches to motorway interchanges and on entry ramps in order to:

- Help manage demand by diverting trips (especially short ones) from motorway to alternates routes during high demand/congested periods;
- Inform motorists of the status of ramp signal operations for entry ramp safety;
- Assist in implementing motorway closures by redirecting motorists before they join the entry ramp; and
- Enable motorists to make choices based on real time travel time information and reassure them of likely journey times to key motorway destinations.

4.3.4.2 High-level technical requirements

Table 4.6 sets out critical high-level technical requirements for VMS in relation to management of traffic entering the motorway.

Table 4.6 High-level technical requirements for VMS to support entry ramp control tools

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.3.4.1	Multi-colour full matrix VMS are installed on each surface road approach (both left and right turn lanes) to motorway entry ramps equipped with CRS or high traffic volumes. Capable of displaying travel time information for up to two destinations for a downstream motorway route; two signs may be required if there is a downstream motorway fork. Must also display freeway closed and other advisory messages as required during an incident, congestion or planned event. Can be referred to as surface road VMS, Real-Time Information Signs (RTIS) or RC3 signs.	Refer to MFG Section 3.11, MFH Section 4.8 and FRSH Section 6.4.12.3 for real-time information signs, including detailed warrants for installation
4.3.4.2	Surface road VMS message displays are automatically or manually changed as part of an integrated LUMS response within the motorway control system. For example, the VMS will display motorway closure and diversion information if required, otherwise travel times will be provided as default during normal conditions.	Refer to MFH Sections 2.7, 2.8 and Appendix A regarding integration of VMS on surface roads and entry ramps with LUMS/VSL
4.3.4.3	Ramp control signs (RC1 and RC2 signs) are installed as required to provide adequate warning to drivers when ramp signals are operating as well as regulatory/advice messages when the freeway ramp is closed. RC2 signs are only required where motorists cannot see the ramp signals on entering the ramp.	Refer to FRSH Sections 6.4.12.1 and 6.4.12.2 for ramp control signs
4.3.4.4	Ramp control sign (RC1 and RC2) message displays are automatically or manually changed as part of integrated CRS operation. For example, they will display 'ramp signals on' and 'prepare to stop' or 'freeway closed' as required.	Refer to FRSH Sections 6.4.12.1 and 6.4.12.2 for electronic ramp control signs
4.3.4.5	Calculate travel times including mainline, ramps and surface road approaches. Mainline travel times are based on detector speed data and spacing; ramp queue delay is calculated by the ramp signal algorithm.	Refer to MFG Section 3.6 and MFH Section 4.2 for calculations of travel times and MFH Section 4.3 for choice of travel time destinations
4.3.4.6	Calculate motorway condition information that provides guidance on the relative level of traffic and delay that may be expected downstream on a particular section of motorway. For example, based on the ratio of the estimated travel time compared to a nominal travel time for the first downstream nominated travel time destination.	Refer to MFH Section 4.2 for calculation of motorway condition information
4.3.4.7	Information displayed on VMS is updated in a timely manner so that it accurately reflects current travel conditions, and minimises traffic entering the ramp following a decision to close the mainline/ramp.	Refer to Section 7 of this Framework for detailed performance requirements

4.3.4.3 Potential future developments

At the time of writing, the following functionalities are also being considered as part of the future development of VMS used for managing traffic entering the motorway and should be considered in Managed Motorways design and operation:

- Better use of VMS at decision points on surface roads that are not in the immediate vicinity of the motorway;
- Modify the logic behind motorway condition information as the message is currently driven off travel time sections which are too long (e.g. 8 km) to provide accurate information at the ramp level, particularly when there is a localised incident. The logic may need a conditional (OR) statement as in an incident that is near the start of a travel time section travel time can be green as once you get past the incident you can travel at the speed limit however the condition most relevant to the motorist is lost in the aggregation/averaging to an overall green;
- Utilisation of other data sources for travel time information (e.g. probe data); and
- Improved functionality and accuracy of travel time algorithms including consideration of predictive travel time algorithms so that motorists become aware of deteriorating and improving travel conditions at the beginning and the end of peak periods respectively; overcoming the current lag in real-time algorithms of up to 15 minutes.

4.3.5 Publication of traffic information to third parties

Providing traffic information to third parties including public transport operators is an important part of reaching road users through channels other than roadside signs. These channels include in-vehicle displays, radio traffic broadcasts, mobile applications and general media alerts. For major incidents, third party traveller information provides access to a wide audience. In other cases, a major advantage of dissemination through tools such as mobile applications and in-vehicle displays is the personalisation of that information to be relevant to that individual road user's travel.

A drawback of relying on dissemination through third parties is the loss of control over the messages that are communicated. It is generally acknowledged however, that road users will access these third party information sources regardless, and therefore efforts by road operators should be focussed on improving the quality of that disseminated information by making road operator data available.

The high-level requirement is therefore simple: to publish all available relevant information in real-time and in a form that is accessible for the greatest beneficial use in communicating up-to-date information to road users.

This Framework will not cover the more detailed requirements for this published information, as they are best covered in other traveller information and/or open data requirements documents.

4.3.6 Vehicle detectors

Vehicle detectors provide real-time data that is critical to the functionality of all control and information tools as well as to support historical network performance evaluation. Historical traffic data is important for helping to resolve operational issues with existing Managed Motorways tools as well as to inform identification of unresolved traffic problems that can lead to more effective targeting and development of future projects. It also assists in development of business cases to justify funding requests.

Current practice is for use of stud or loop detectors that collect speed, volume and occupancy (SVO) data.

4.3.6.1 High-level functional requirements

Vehicle detectors must provide real-time and high-quality/ accurate traffic data that enables:

- Real-time 24/7 mainline capacity management by:
 - Simultaneous detection and control of multiple bottlenecks (individual shockwaves), no matter where or when they occur on the motorway network
 - Detecting queues on ramps/arterials
 - Supporting calculation of critical/target occupancies for control under a range of traffic and network conditions
 - Supporting operational tuning of algorithms – both historical trends (setting ranges) and real-time absolute values
 - Monitoring and reporting of real-time operational performance and network conditions (including reproduction of fundamental diagrams);
- Calculation of travel times for display on surface road and mainline VMS; and
- Operation of SCATS at surface road interfaces to the motorway (and any future Arterial Road Management System).

The algorithms used for entry ramp control are dependent on specific data requirements from detectors, which reflect the variable and volatile nature of traffic flow (refer to Section 3.1.4.3). It is therefore imperative that the specific data type, quality and timeliness requirements of these algorithms are met, not only by the detectors, but also throughout the full process flow feeding data from the detectors to the algorithms. The timeliness of the full data flow process throughout the tool chain is discussed in more detail in Section 7.1.

4.3.6.2 High-level technical requirements

Table 4.7 sets out critical high-level technical requirements for vehicle detectors in relation to management of traffic entering the motorway.

4.3.6.3 Potential future developments

At the time of writing, the following functionalities are also being considered as part of the future development of vehicle detectors used for managing traffic entering the motorway and should be considered in Managed Motorways design and operation:

- Collection of better quality classification data to improve occupancy/capacity estimations;
- Reduction in number of faulty detectors to improve accuracy of HERO LIVE estimations;
- Continuing enhancements to improve the quality of data fed into the algorithm;
- Automated identification of problematic detector data; and
- Fusion of data sources from motorway and surface road detectors, as well as probe vehicle data, to improve data quality.

4.3.7 CCTV

CCTV gives operators in the TMC visibility of the road network and provides an important tool for operators to verify the occurrence of incidents, congestion and events detected by other sources such as vehicle detectors and automatic incident detection systems. It also assists in management of incidents and investigation of operational performance issues.

Table 4.7 High-level technical requirements for vehicle detection to support entry ramp control tools

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.3.6.1	SVO detectors installed that collect data on occupancy (as surrogate for density, the critical input for mainline control), speed and volume (secondary measures for ramp demand/queue estimation). At the required accuracy for control in both free-flowing and congested periods (i.e. moving and stationary vehicles). Vehicle classification data is also required for occupancy estimations.	Refer to FRSH Section 5.1 & 5.2.2 on data quality and attributes. Refer to Section 7 of this Framework for detailed performance requirements
4.3.6.2	SVO data coverage to include all lanes on mainline and all entry/exit ramps. Detectors positioned at appropriate locations for control of all merge points and critical bottlenecks (so HERO can match capacity to both) on the mainline, as well as ramp queue/delay estimations.	Refer to FRSH Section 5.2.1 for detector spacing/positioning
4.3.6.3	Data quality is managed, including: <ul style="list-style-type: none"> Data smoothed and filtered in real-time to understand ground truth and calculate stable control values for true control points Data substituted from other working lanes or adjacent control points to provide near optimal operations when detector faults are experienced Data quality assessed for suitability to support real-time operations (i.e. ensure that within approved thresholds, accepting that reduced quality from minor faults may lead to reduced capability to optimise. Major faults may mean that dynamic operation is not possible). 	These requirements were identified during previous system development and now form part of STREAMS/HERO LIVE
4.3.6.4	Data collected at appropriate frequencies to enable changes in traffic conditions and ramp attributes to be detected as soon to the actual event as possible. Data smoothed/processed and fed back to control regulators with minimal delay/latency to enable required control response in the field i.e. precise control of the mainline volumes at near critical flows.	Refer to FRSH Sections 5.2.2 and 5.2.5 for timeliness of data collection/processing. Refer to Section 7 of this Framework for detailed technical requirements
4.3.6.5	Detectors installed as standard for SCATS operation.	Refer to TCS 054 – 2 – 2012
4.3.6.6	Detector performance is consistent throughout a freeway route to simplify management of multiple bottlenecks along the route (this may require consistency of detector types).	Refer to TCS 048 – A – 2014
4.3.6.7	System includes tools that display on the HMI to assist operators with analysis of data and optimisation of control tools.	Refer to FRSH Section 5.3 for data analysis tools

4.3.7.1 High-level functional requirements

CCTV must enable real-time monitoring and verification of network conditions to support:

- CRS algorithm tuning and optimisation, including visual confirmation of unique ramp attributes (of which there are over 400 for each ramp) and queue overspill to surface roads, and identification of problematic detector data;
- SCATS optimisation, including monitoring of queue lengths; and
- Incident management, in the event of a ramp/motorway closure.

4.3.7.2 High-level technical requirements

Table 4.8 sets out critical high-level technical requirements for CCTV in relation to management of traffic entering the motorway.

Table 4.8 High-level technical requirements for CCTV to support entry ramp control tools

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.3.7.1	Cameras installed with pan, tilt and zoom capability that provide as a minimum full (preferably overlapping) coverage of the entry ramps, surface road approaches and motorway merges/bottlenecks on the mainline. Overlapping coverage means where one location can be observed by two cameras to improve operational flexibility and system redundancy. Coverage means ability to identify individual vehicles and other objects (stationary or moving) on the network, at a level of detail in accordance with TMC operational requirements.	Refer to FRSH Section 6.4.15, MFH Section 2.9 and MFG Section 3.3 for CCTV coverage/visibility
4.3.7.2	CCTV operated via both programmable pre-sets as well as operator override in the case of an incident, event, works or congestion.	N/A
4.3.7.3	CCTV viewable by TMC operators on a map based GUI with scrolling image software.	N/A
4.3.7.4	Frequent refresh rate to ensure operator is alerted to any change in conditions.	Refer to Section 8 of this document for detailed technical requirements
4.3.7.5	CCTV displays from one operator can be shared and displayed in GUIs of other operators.	N/A

4.3.7.3 Potential future developments

At the time of writing, the following functionalities are also being considered as part of the future development of CCTV used for managing traffic entering the motorway and should be considered in Managed Motorways design and operation:

- CCTV to provide more advanced detection of slow moving or stationary vehicles and provide alarms to operators (e.g. a basic automatic incident detection system); and
- Automated selection of CCTV images in the TMC to focus on deteriorating traffic conditions (e.g. observe slow moving traffic locations detected by SVO data).

4.4 Managing traffic on the motorway

The primary means to control traffic on the motorway is through management of traffic speeds and lane use. Lane use management systems (LUMS) which include variable speed limit (VSL) functionality are intervention tools that provide operators with the ability to make the best use of the available road space and maintain road safety in response to changing network conditions.

Dynamic variable speed limits (DVSL) are an optimisation control tool under development to support the CRS system in optimising mainline capacity through mainline metering.

The control tools for managing traffic on the motorway mainline are supported by the following chain of foundation tools:

- Mainline variable message signs, which provide information to enable informed route choices and advise motorists of changing motorway conditions (and are supported by VMS provided at interchanges and on surface roads);
- Traffic detectors, which provide data and control points for DVSL control algorithms as well as support to AID and queue detection/queue protection and weather algorithms; and
- CCTV, which provides visual monitoring of mainline operations and assists in verification and management of incidents.

The system must also be integrated with other control tools installed at the surface road interfaces, such as (refer to Sections 4.3, 4.5 and 4.6):

- CRS, which controls the demand onto the motorway at each entry ramp so as to manage mainline capacity;
- Entry ramp management system, which acts to significantly reduce entry ramp flows and/or to close ramps in the event of motorway lane or full closures, to avoid vehicles being trapped on the freeway and accelerate recovery from flow breakdown;
- Exit ramp management system, to assist the management of queues on exit ramps and reduce efficiency and safety impacts on mainline traffic;
- Wide Area Network Dispersion strategies, which may use mainline LUMS and VMS to assist in advanced rerouting of motorway traffic following a major incident or severe congestion; and
- DVSL on intersecting routes, which assists CRS in managing mainline capacity and bottlenecks, and safety at back of queues.

The following sections provide operational policies (for control tools only) and critical high-level functional and technical requirements for each tool that contributes to managing traffic entering the motorway.

4.4.1 Integrated speed and lane use management (LUMS)

Lane use management systems (LUMS), which also include variable speed limit (VSL) functionality, are an intervention control tool that responds to changes in network and traffic conditions as a result of an incident, congestion or adverse weather. They allow operators to make the best use of available capacity depending on current conditions or to open up additional capacity on the road. This may include enabling use of the emergency lane as a running lane on a full-time (all lane running) or part-time (part-time emergency lane running) basis, or operation of reversible lane systems. LUMS can also incorporate VSL algorithms that improve route based safety by reducing speed limits in response to traffic events, such as the queue detection/queue protection algorithm and the weather algorithm.

Further detail on the current and proposed future operational architecture and rules for LUMS is provided in Appendix B. Within STREAMS, LUMS provides the overarching rules engine for management of intervention control and manages multiple requests for changes to lane status, speed limits and VMS displays (for electronic signals and signs on mainline, ramps and surface roads).

4.4.1.1 High-level functional requirements

LUMS including VSL must provide real-time control of lane use and speed limits in response to changing traffic conditions (including incidents, congestion, works and weather events), that enables:

- Safe management of traffic, governed by a common set of agreed operating rules and principles (within a hierarchical response);
- Consistent and accurate display of messages across each lane within a site, and between consecutive sites (particularly where visible downstream);
- Recovery of traffic flows and speeds to normal as soon as possible following an incident; and
- Optimal use of road space as required, for example by all lane running (ALR) and part-time emergency lane running (ELR) operation.

4.4.1.2 Operational policy

Operational rules and policies have been developed to ensure safe and efficient operation by ensuring that hazardous, illogical, conflicting and ambiguous combinations of signs across the LUMS system are prevented. Policies and rules cover lane control, speed control, longitudinal propagation along the freeway, emergency access, entry and exit ramp management, surface road and motorway mainline VMS and ramp control signs (RC1 and RC2).

In the event of an incident, the following operational policies are applied:

- Sign displays at the first site immediately upstream of an incident are set to a safe speed limit and lane configuration; then
- Subsequent upstream gantries display a sequence of speed limit reductions and lane closure instructions, with appropriate buffering/tapering; and
- Gantries immediately downstream of the incident indicate normal default speed limits and lane status.
- In the event of congestion, the following operational policies are applied:
- Match speed limit to congested traffic speed; then
- Protect back of queue by slowing vehicles approaching congestion, with appropriate buffering of speed limit reductions on sequential gantries.

Operational policies for DVSL Flow Stability and Mainline Bottleneck Management algorithms where DVSL is applied are described in Section 4.4.2. Operational policies for part-time shoulder use and reversible lanes may also be applied as required.

In the event of adverse weather or environmental conditions, the following operational policies are applied:

- Allow settling time to ensure weather conditions are stable; then
- Match speed to safe travel speed for prevailing conditions; then
- Subsequent upstream gantries display a sequence of speed limit reductions with appropriate buffering.

The hierarchy of display of lane status and speed limits is as follows (highest priority first):

- Lane closed display, then
- Lane closing display, then
- Exit arrow display, then
- Speed display (where lowest speed request is highest priority speed request).

All LUMS operations must comply with Victorian Road Traffic Regulations and Road Rules.

The increased deployment of LUMS on motorway routes increases the likelihood of situations where coordination is required between multiple applications of LUMS along one route (e.g. an incident and a work site) and between applications of LUMS on intersecting routes. The complexity of this coordination is increased by the overlapping nature of the timeframes for different LUMS applications, such that the start and end times of different LUMS applications are unlikely to align.

Further detail on policy and rules is provided in the MFH Section 2.6 to 2.8, and Appendix A.

4.4.1.3 High-level technical requirements

Table 4.9 sets out critical high-level technical requirements based on the operational policy for LUMS.

Table 4.9 High-level technical requirements for LUMS

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.4.1.1	Regulatory lane use signs (with functionality to display lane control symbols and VSL) mounted centrally over each running lane on gantries to provide lane specific instructions. Where All Lane Running or part-time Emergency Lane Running is in use, signs must also be displayed over the emergency lane. For reversible lane systems, signs must be provided for each direction. VSL provided at all entry ramps within LUMS area. Signs use LEDs in full matrix or pre-formed shapes.	Refer to MFH Sections 2.2 to 2.5 & Section 3.4 for devices and standards
4.4.1.2	LUMS gantries at appropriate locations for managing traffic within interchanges and at consistent spacing on mainline to ensure that drivers see a sign within adequate travel time for short term memory retention, and to provide appropriate distances for sequential operational transitions (i.e. for buffering of speed limit reductions and tapering of lane closures). Should also consider operational requirements in the event that there is a major fault and a sign array is not working. Tunnel environments require closer spacing to ensure a downstream sign is always visible.	Refer to MFH Section 2.5 for longitudinal positioning
4.4.1.3	LUMS requests can be generated via multiple triggers, including automatic (algorithmic) responses, pre-defined response plans and manual request (by operator).	This requirement was identified during previous system development and now forms part of STREAMS – refer to Appendix B for further detail
4.4.1.4	Automatic (algorithmic) requests may include algorithms for Queue Detection/Queue Protection, Automatic Incident Detection, Weather and Flow Stability and Mainline Bottleneck Management through DVSL. It must be possible to control the influence of different algorithms by time-of-day/ current traffic conditions.	Refer to MFH Sections 3.6 to 3.7, and Section 4.4.2 and Appendix B of this Framework regarding DVSL algorithms
4.4.1.5	For a manual request, the system provides visual display of the proposed LUMS schematic, which the operator can then modify subject to certain rules. For example, a speed limit display can only be changed to a lower speed limit or lane control display, and a lane control display can only be changed to another lane control display.	Refer to MFH Sections 3.6 to 3.7
4.4.1.6	Pre-defined response plans are developed and saved using LUMS schematics that can be activated when needed. For example, if required to address a specific combination of one or more lane closures. Plans can be time-based or manually activated. Plans may include LUMS responses for changing the priority use of a lane or opening a part-time lane traffic (whether on fixed time schedule or in response to a situation).	This requirements was identified during previous system development and now forms part of STREAMS
4.4.1.7	Multiple simultaneous LUMS requests are managed by merging to develop a single LUMS response for affected sections of network.	This requirement was identified during previous system development and now forms part of STREAMS
4.4.1.8	LUMS response displayed on a schematic within the GUI that allows operator to visualise the speed and lane control changes within the affected sections of network, as well as other responses for VMS and CRS etc.	This requirement was identified during previous system development and now forms part of STREAMS
4.4.1.9	LUMS response submitted to a Rules Engine which checks that LUMS responses are compliant with rules governing lane closures/speed limit changes before implementation. For example, rules may relate to maximum speeds permissible next to lane closures, lane closure tapering requirements, blanking of signs, speed buffers and implementation transitions (i.e. using flashing annulus and crosses). Rules in Rules Engine categorised as fundamental rules (which cannot be modified/broken) and policy rules (which can be modified by an operator).	Refer to MFH Section 2.6 and Appendix A for operating policies rules
4.4.1.10	System enables re-configuration of policy rules by an operator, usually as part of setting up pre-defined plans. If a policy rule is changed, then it must be automatically updated to all relevant plans, or where this is impractical or may have undesirable consequences, an alert for out-dated plans must be created.	This requirement was identified during previous system development and now forms part of STREAMS
4.4.1.11	Optional requirement for LUMS responses to be manually approved by an operator prior to implementation ('operator assist'), otherwise done automatically. As a minimum, notification provided to operator of any responses implemented automatically.	N/A
4.4.1.12	Sign controller interlock provided for each LUMS gantry for verification of operating rules and policies before display, to provide safety reassurance in the case of an error in data transmission etc. Fundamental rules are checked for example, no differential speeds allowed at one site, and a lane merge signal can't point towards a closed lane.	VRT 904-3.0 2011 (VicRoads 2011), Section 3.13 (Interlocking)
4.4.1.13	TMC operators are able to remotely override automated LUMS responses if inappropriate to current traffic conditions. For example, to prevent late re-opening of lanes and unnecessary lane closures or speed limit drops	N/A

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.4.1.14	Once the need for intervention has been detected, the selection/generation of LUMS responses and subsequent implementation of LUMS response in the field (following operator approval) must be completed within minimal delay/latency, to ensure that the response is appropriate for current network conditions.	Refer to Section 7 of this Framework for detailed performance requirements
4.4.1.15	Change of LUMS displays on affected signs/gantries in field occurs within narrow timeframe so motorists travelling along motorway sections do not receive conflicting and dangerous messages.	Refer to Section 9 of this Framework for detailed requirements
4.4.1.16	Weather algorithm triggered by data on different weather events, including heavy rain, strong winds, poor visibility, low surface friction. System can be configured and tuned in relation to parameters such as settling time, deactivation time, speed reduction for different scenarios and the defined zone of influence for each detector.	This requirement was identified during previous system development and now forms part of STREAMS
4.4.1.17	Queue Detection/Queue Protection algorithm based on speed and density data from upstream mainline detectors. Measure propagation speed of queue and calculate required changes to upstream gantry displays to provide appropriate speed buffer in advance of back of queue. System can be configured and tuned to minimise the false alarm rate.	N/A
4.4.1.18	System configured to operate with tight tolerances with respect to lane closing/opening, to prevent unnecessary reductions or restrictions in capacity that can take a long time to recover from.	N/A
4.4.1.19	LUMS request must be raised with minimal display/latency following detection of event by algorithms to ensure a response can be activated as soon as possible.	Refer to Section 7 of this Framework for detailed performance requirements
4.4.1.20	Integration of LUMS software between different operators, to ensure that a single LUMS plan can be implemented across jurisdictional boundaries as required for safe traffic management. Systems accept data from other operators for both upstream and downstream conditions to generate a relevant and suitable field response. Each operator sees data displayed on the single GUI.	N/A
4.4.1.21	LUMS is integrated with DVSL, and the Rules Engine configured to ensure no conflict between rules for each system. For example, DVSL should operate 24/7 to support route optimisation, however if LUMS is deployed then the lower speed limit should always be displayed. DVSL may then continue to regulate speed limits if lowered by LUMS.	This requirement was identified during previous system development and will form part of STREAMS
4.4.1.22	Integrated with AID, CCTV and congestion alarms to identify and confirm problems that may require LUMS responses as well as confirm actions taken are effective in field.	N/A
4.4.1.23	Integrated with upstream mainline VMS and surface road VMS to provide advance information to motorists of speed limit and lane status changes, including cause of event and diversion advice to assist with compliance. The VMS message must match the event description and LUMS arrangement.	Refer to MFH Section 2.7 for integration with VMS
4.4.1.24	Integrated with CRS, to provide CRS control algorithm with information on available lane capacity (to ensure accurate capacity estimations) and current speed limit values (to prevent ramp signals from being falsely triggered by a speed limit lower than default).	Refer to MFH Section 2.8 for integration with CRS
4.4.1.25	LUMS operates effectively through motorway merges and diverges, and can operate a network of motorways by control of traffic through motorway-to-motorway interchanges.	N/A
4.4.1.26	Integrated with WAND to provide lane and speed status to WAND and to implement changes to lane and speed status required by WAND.	Refer to Section 4.5.2 of this Framework for further information on WAND

4.4.1.4 Potential future developments:

At the time of writing, the following functionalities are also being considered as part of the future development of LUMS and should be considered in Managed Motorways design and operation:

- Strategy Manger triggers pre-defined response plans e.g. if a Traffic Control Plan for a tunnel is activated which requires complimentary LUMS response on other sections of road;
- Assess current LUMS operating policies and rules to ensure they work across multiple motorway networks and modify as necessary e.g. a motorway to motorway interchange;
- Dynamic LUMS that improve on the operational benefits through increased throughput and safety & awareness due to their adaptive nature. The first step is to develop DVSL to operate with LUMS. The second step would be pre-empting lane and carriageway closures with alarms to the operators;
- Additional LUMS policies and rules using additional lane symbols to address more complex network configurations (such as at motorway to motorway interchanges); and

- Additions to standard message libraries of more complex VMS displays that are combinations of diagrams and lane control symbols to advise motorists of incident conditions ahead and the available lanes and route choices.

4.4.2 Dynamic Variable Speed Limits (DVSL)

Dynamic variable speed limits (DVSL) are an optimisation control tool that can support the CRS system in optimising mainline capacity through mainline metering. It works by slowing traffic on approach to a bottleneck in order to create a ‘managed bottleneck’ with more dense traffic and improved flow stability, so as to avoid flow breakdown occurring at a critical bottleneck downstream. This tool is currently in development and will be fully integrated with CRS to ensure the systems are complimentary (not conflicting) and thereby achieve greater cumulative benefits.

The DVSL function provides for the implementation of the Flow Stability and Mainline Bottleneck Management algorithm. This tool is in development at time of publication and has undergone initial live testing. The existing High Flow algorithm in STREAMS has a similar intent, however it has been assessed as not suitable for use in the Victorian motorway network. Within STREAMS, the new DVSL algorithms will be managed through an expanded LUMS functionality.

Although VicRoads currently operates (semi-)automated VSL, the operation is not dynamic – refer to Table 4.10 for the differences between dynamic and automated operation. An earlier system used on the M80 Ring Road was dynamic, however it was not designed for use with CRS and is not currently in use. Algorithm elements under development and testing for VicRoads (DVSL Flow Stability and Mainline Bottleneck Management) would re-introduce dynamic operation of VSL to Melbourne.

Table 4.10 Dynamic versus automated variable speed limits

Level of active management	Speeds varied for	Why the change in speed limit occurs
Dynamic Route optimisation	Flow stability	Before flow breakdown occurs, to improve optimisation of flow and employ mainline metering upstream of bottleneck area
	Bottleneck resolution	After flow breakdown occurs, use upstream mainline metering to assist recovery of stable flow
Automated Traffic management and control interventions	Queue detection and protection	Protect back of queue to improve safety and reduce secondary incidents
	Incidents/events	Provide safe speeds for the changed conditions through semi-automated response plans
	Weather (wind)	(Semi-)automated response based on detected wind speeds

4.4.2.1 High-level functional requirements

Control the mainline traffic speed as required on a 24/7 basis to support CRS in managing mainline flows within a critical occupancy (density). This occurs by reducing the flow of traffic into key bottleneck areas through the application of reduced speeds. In some cases this will create flow breakdown in any area where it is better able to be accommodated to improve overall route and network performance. This ability to create a bottleneck through the application of reduced speeds upstream can also be applied to resolve flow breakdown that has occurred.

4.4.2.2 Operational policy

As traffic demand increases, the policy for control optimisation is as follows:

- Generally CRS would activate to optimise throughput; then
- During CRS operation, DVSL may activate if traffic flow deteriorates to assist CRS by increasing densities, homogenising traffic speeds and metering of mainline (e.g. lower VSL upstream of bottleneck).

If flow breakdown occurs and significantly longer travel times are detected, then may be overridden by other LUMS intervention control algorithms.

It is not yet VicRoads operational policy to use lower upstream speed limits to create a managed bottleneck to resolve flow breakdown that has already occurred or is likely to occur. This functionality is in development as part of a trial in Melbourne and once adequately tested, then this aspect of DVSL operation should be included within operational policy.

4.4.2.3 High-level technical requirements

Table 4.11 sets out critical high-level technical requirements for DVSL. These requirements are relatively generic, since the DVSL algorithm is still in development.

Table 4.11 High-level technical requirements for DVSL

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.4.2.1	Signs for DVSL are integrated with LUMS or side-mounted at appropriate and consistent spacing on the mainline for safe and compliant operations. DVSL required on all entry ramps within DVSL/LUMS area.	MFH Section 3.4 on devices/ standards Refer to MFH Sections 2.5.3 and 3.5.1 on mounting and longitudinal positioning
4.4.2.2	DVSL activate and deactivate automatically when warranted by motorway conditions without operator intervention. DVSL will only activate when certain thresholds are exceeded. Adjustable controls in place to prevent activation/deactivation when undesired.	N/A
4.4.2.3	DVSL calculations must be updated in a timely manner as required for system to respond to changes due to vehicle mix and traffic changes.	Refer to Section 7 of this Framework for detailed performance requirements
4.4.2.4	When DVSL algorithm triggers a response, it is submitted to CRS and LUMS software for merging with other responses, display on LUMS schematic/GUI and submission to the Rules Engine. There is an optional requirement for operator approval of response prior to field implementation.	Refer to Appendix B of this Framework for further description of request merges.
4.4.2.5	DVSL operates effectively through freeway merges and diverges, and can operate a network of motorways by control of traffic through motorway-to-motorway interchanges.	N/A
4.4.2.6	TMC operators have the ability to remotely override DVSL in the case of a major fault or inappropriate speed limits being displayed.	N/A
4.4.2.7	System can be manually tuned during operations and thresholds adjusted.	N/A
4.4.2.8	DVSL algorithm integrated with CRS to work cooperatively in management of mainline bottlenecks.	Refer to MFH Section 3.6.4

4.4.3 Variable Message Signs (VMS)

Similar to surface road VMS, mainline VMS are multi-functional and allow display of different message types for normal conditions (travel time information) and during incidents, congestion or planned events, as required. They are larger in size than surface road VMS to meet requirements for a different speed environment. Refer to MFH Section 4 and Appendix B for further information on the control hierarchy for message displays and guidance on approved pictogram and message text displays.

4.4.3.1 High-level functional requirements

Mainline VMS must provide reliable, real-time information displayed on the motorway mainline to:

- Provide advance information on downstream travel conditions, including incidents, works, and weather events;
- Improve safety and compliance with LUMS instructions (for example by explaining the cause of an incident), and reduce likelihood of secondary crashes;
- Help manage demand by diverting trips from motorway to alternates routes during high demand/congested periods and incidents;
- Enable motorists to make choices based on real time travel time information to downstream motorway destinations, and coloured indication of likely conditions (delays relative to nominal travel times); and
- Display other road safety campaign messages when the VMS are not required for higher priority messages.

4.4.3.2 High-level technical requirements

Table 4.12 sets out critical high-level technical requirements for mainline VMS.

Table 4.12 High-level technical requirements for VMS to support mainline control tools

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.4.3.1	Multi-colour full matrix VMS installed on mainline in advance of decision-making points and with regular spacing in between subject to other considerations. Side-mounted or overhead-mounted. VMS required in advance of LUMS/DVSL section so can warn motorists of lane status and speed limit changes. Capable of displaying up to three travel times/destinations and pictogram.	Refer to MFH Section 4.5.3 for mainline VMS design principles
4.4.3.2	Travel times calculated based on mainline detector speed data with frequent updates so that reflect current conditions. Consideration may be given to supplementing detector data with probe vehicle data, however as this would not reduce the other needs that drive detector provision, this may be relevant only in limited circumstances.	Refer to Section 7 of this Framework for detailed performance requirements
4.4.3.3	VMS integrated with LUMS software so that TMC operators are able to activate manual and automated plans based on VicRoads operating policies and rules. Plans may override travel time information, so as to provide tailored messaging for a specific event.	Refer to MFH Section 2.7 LUMS Integration with Other Freeway Devices, and MFH Appendix A and Appendix B for LUMS policy rules and pictograms
4.4.3.4	VMS messages displayed on schematic in GUI with other responses, such as LUMS, DVSL and CRS. VMS messages part of combined LUMS response that is submitted to Rules Engine to check against VicRoads operating policies and rules. VMS responses may be implemented automatically by the system or only after operator approval.	Refer to MFH Section 2.7, 4.5.4 and Appendix A for integration between devices and operating policies/rules
4.4.3.5	Plans may affect multiple VMS displays e.g. include a main and supplementary message on consecutive mainline gantries, as well as displays on surface road and entry ramp VMS. As per LUMS, VMS must also be integrated with VMS systems of other operators to enable VMS plans to be implemented across operator boundaries.	N/A
4.4.3.6	TMC operators may override automated plans before and after implementation.	Refer to MFH Section 4.5.5
4.4.3.7	Information displayed on the VMS updated in a timely manner so that message is appropriate for downstream travel conditions.	Refer to Section 7 of this Framework for detailed performance requirements

Please note that in the MFG and MFH, Trip Information Signs (TIS) and Trip Condition Sign (TCS) are superseded by VMS which are used for their greater flexibility in displaying different types of messages.

4.4.3.3 Potential future developments

At the time of writing, the following functionalities are also being considered as part of the future development of mainline VMS and should be considered in Managed Motorways design and operation:

- Graphical displays of diversion information showing congested sections of the alternate routes (similar to Graphical Route Information Panels); such display approaches will require VMS to be capable of full colour and full matrix display over the full width of the sign;
- Future motorway projects to assess current VMS rules and policies to ensure they work across multiple freeway networks and to modify as necessary;
- Add flashing displays for severe congestion condition information as per guidelines; Appendix D in FRSH and Section 4.8.5.1 of MFH;



Figure 4.1 A SWARCO full matrix LED sign in Bavaria, Germany (left) and a full matrix LED sign in Holland (right)

- Develop new rules and messaging for major traffic diversion using traveller information around major blockages in the network; and
- Refer also to WAND (Section 4.5.2).

4.4.4 Publication of traffic information to third parties

Refer to Section 4.3.5 for discussion.

4.4.5 Automated Incident Detection (AID)

The current AID algorithms in STREAMS are designed to detect incidents by looking for disruption in the traffic flow at downstream (and upstream) detector sites. There is a statistical algorithm and comparative algorithm, which both use volume and occupancy data (historical and real-time). Earlier in 2014, the Victorian Auditor General identified AID as a tool warranting greater use by VicRoads.

VicRoads has not yet used either algorithm and plans to undertake further investigation to identify an appropriate AID system. This system may be based on an enhanced SVO based algorithm approach, a CCTV/video image based approach or an alternative approach such as infrared detection. In the interim, once ready for adoption the STREAMS Queue Detection/Queue Protection may allow for detection of traffic queues caused by incidents.

4.4.5.1 High-level functional requirements

AID must provide fast and reliable detection of all incidents (in real-time) that occur on the motorway mainline, to enable faster incident response and earlier incident removal/recovery to normal conditions.

'Incidents' for detection may include traffic events (e.g. speed change, congestion, stopped vehicle, wrong way vehicle) as well as other events such as a pedestrian or debris on the road.

4.4.5.2 High-level technical requirements

Table 4.13 sets out critical high-level technical requirements for AID. The following requirements are relatively generic, since a specific AID algorithm or approach has not yet been selected for use by VicRoads. These generic requirements best reflect an approach of using algorithms to analyse vehicle detector data but also have some applicability to other approaches.

Table 4.13 High-level technical requirements for AID to support mainline control tools

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.4.5.1	Algorithms detect disruption at a lane level before aggregating to a site level.	N/A
4.4.5.2	System can manage multiple simultaneous events.	N/A
4.4.5.3	Accurate identification of incidents with a low false alarm rate to ensure credibility.	Refer to Section 7 of this document for detailed performance requirements
4.4.5.4	Multiple algorithms used to minimise false alarm rate and ensure achieve high performance is achieved in all traffic conditions (since no one algorithm has proven to provide optimal performance for all conditions). Triggers from at least two algorithms are required for system to raise a notification of a potential incident to the operator.	N/A
4.4.5.5	Integration with LUMS, DVSL, CRS and VMS so that all tools can be coordinated to provide an appropriate field response once an incident is detected.	N/A
4.4.5.6	Once a potential incident has been detected, notification to the operator/LUMS must be provided with minimal delay/latency, to ensure that the response can be implemented as soon as possible and is appropriate to current conditions.	Refer to Section 9 of this document for detailed technical requirements
4.4.5.7	Integration with CCTV to provide automated display of the identified incident location	N/A

4.4.6 Vehicle detectors

4.4.6.1 High-level functional requirements

Vehicle detectors must provide real time and high-quality/accurate traffic data that enables:

- 24/7 mainline capacity management by CRS and DVSL (refer to Section 4.3.5), including operational tuning of algorithms and monitoring of performance;
- Calculation of mainline travel times for display on VMS; and
- Timely and reliable detection of incidents and congestion, as required for AID and Queue Detection/Queue Protection algorithms.

4.4.6.2 High-level technical requirements

Table 4.14 sets out critical high-level technical requirements for vehicle detectors used to manage traffic on the motorway mainline.

Table 4.14 High-level technical requirements for vehicle detectors to support mainline control tools

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.4.6.1	<p>SVO data and performance requirements as outlined in Table 4.7 (Section 4.3.6) and Section 7 (where relates to mainline devices), with the following additions:</p> <ul style="list-style-type: none"> • Spacing of detectors on mainline at appropriate intervals for timely queue detection (longer spacing means longer detection time). • Detectors must be included in all lanes open to traffic at any time, including part-time lanes • Consideration should be given to installation of detectors in emergency stopping bays to detect the presence of a vehicle (and provide an automated alert to the operator) 	Refer to Section 2.10 of MFH on emergency lane use

4.4.6.3 Potential future developments

As per Section 4.3.6.

4.4.7 CCTV

4.4.7.1 High-level functional requirements

CCTV must provide 24/7 real-time monitoring and verification of traffic operations to support:

- Timely detection of incidents, congestion and weather events;
- LUMS operation and management of congestion and incidents;
- DVSL algorithm tuning and optimisation; and
- Other operational functions.

4.4.7.2 High-level technical requirements

Table 4.15 sets out critical high-level technical requirements for CCTV used to help manage traffic on the motorway mainline.

Table 4.15 High-level technical requirements for CCTV to support mainline control tools

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.4.7.1	<p>As outlined in Table 4.8 (Section 4.3.7), with following additions:</p> <ul style="list-style-type: none"> • Full coverage provided of mainline carriageways, with adequate spacing for visibility requirements. Complex and critical locations require overlapping CCTV coverage to improve congestion and incident management (i.e. by enabling observation of incidents from multiple directions and using separate cameras for incident management and monitoring of upstream traffic). For areas without emergency stopping lanes or with reversible lanes, overlapping CCTV coverage may be required. • CCTV should also provide coverage of emergency stopping bays. • CCTV or separate webcams may be used to provide fixed images of the motorway for display to public on VicRoads website or dissemination to media. 	Refer to MFH Section 2.9 and MFG Sections 2.4 and 3.3

4.4.7.3 Potential future developments

As per Section 4.3.7.3.

4.4.8 Congestion alarms

Congestion alarms may be provided in the future to assist operators to manage traffic in real-time by drawing their attention to problems to be addressed. The alarms may also assist optimisation tuning by highlighting occasions where congestion occurred for post-analysis and review.

A number of the intervention, optimisation and information functions already in use or proposed by use by VicRoads contain similar elements to what might be included in congestion alarms. Examples of this include the activation criteria for CRS, the red/heavy band for travel times and queue detection functions for LUMS.

4.4.9 Weather and environmental monitoring

In certain circumstances, environmental monitoring and control systems may be appropriate because of the prevailing weather conditions at the location. On certain freeways in Victoria, ice detection and warning systems and weather stations have been implemented to advise drivers of possible traffic hazards (such as fog, ice, high winds and/ or flooding) and to improve road safety. The West Gate Bridge has an environmental monitoring system which includes monitoring of wind speeds and is an example where environmental conditions are an input to a control function, in this case variable speed limits.

The current LUMS system does include some requests that are activated by weather detectors on the network, as described in Appendix B.

Given the breadth of applications, limited general guidance is available for environmental monitoring systems, and provision is to be on the basis of benefits and costs of individual proposals. Proposals related to ice must consider the Black Ice Management Policy.

On Managed Motorways sections where the conversion of shoulders into running lanes means that water spreads from drainage may impinge on active lanes, suitable environmental detectors are required. These detectors may work on changes in surface friction, the presence of surface water or the rate of rainfall as appropriate to trigger a suitable traffic management response to mitigate the elevated risk.

4.5 Managing traffic exiting the motorway

Managing traffic exiting the motorway is critical to ensure effective dispersion of motorway traffic without causing congestion on the connecting surface road network, as well as to ensure that exiting traffic does not back up and interfere with mainline flow. Special consideration needs to be given to maintaining priority for road based public transport.

There are a number of strategies that can be applied, including management of exit ramps and the surface road interface, wide area network dispersion and end-of-motorway management. These strategies are still in the early stages of development by VicRoads but utilise many of the same tools as for management of entering and mainline motorway traffic.

Managing traffic exiting the motorway includes control optimisation tools (such as arterial traffic signal control), control intervention tools (such as LUMS including VSL) and VMS for provision of traveller information to aid with motorway traffic dispersion and re-routing during incidents and congestion. Integration between arterial and motorway control systems is critical for effective implementation of these strategies.

Managing exiting traffic is important at all times, but takes on particular importance during major incidents and severe congestion events on the motorway mainline that may result in part or full carriageway closures and vehicles (and their occupants) being trapped in the freeway system. During these times, greater priority needs to be given to releasing vehicles from exit ramps into the surface road network, with special signal release phases and/or lengthy dwells covering not just the interchange but also nearby intersections to provide progression of traffic away from the motorway.

The following sections provide further explanation of the operational strategies that are being developed by VicRoads for management of traffic exiting the freeway. Operational policies (for control tools only) and critical high-level functional and technical requirements are provided if available.

4.5.1 Exit ramp management including arterial road interface management

Exit ramp queues may exceed the available ramp storage as a result of high exit demands and ineffective management of the surface road intersection and connecting routes. High exit ramp flows may be a reoccurring issue during peak periods or as a result of a major incident or severe congestion event on the mainline. If exit ramp flows back up on the motorway then this will reduce the mainline capacity and may result in flow breakdown, as well as safety issues associated with queuing traffic in a high-speed environment.

Traditionally exit ramp management has solely relied on operation of the arterial traffic control system, SCATS, and associated loop detectors. VicRoads is exploring options to better integrate the operation of the surface road intersection with motorway operations. The new strategy will be automated and system-wide, to ensure a coordinated network response that optimises both surface road and motorway operations.

This may include use of the following tools (as recommended in Austroads 2014):

- CCTV coverage of the exit ramp and surface road intersection/approaches to monitor arterial operations;
- Back-of-queue detectors installed on exit ramp to report ramp demand;
- Adjustment of traffic signal timings at the interchange and along connecting arterial routes;
- Use of VMS on the mainline to warn drivers of delays on the exit-ramp and encourage use of alternative exits;
- LUMS for dynamic lane management on the motorway mainline and exit ramps; and
- VSL on the mainline to provide back-of-queue protection.

The strategy is still in development and hence only limited information is available regarding system requirements. In the future, entry ramp management systems may be used as part of the dynamic re-configuration of the motorway system to open/close entry and exit ramps based on the need to manage demand to and from the motorway system (refer to Section 4.2 for further detail).

4.5.1.1 High-level functional requirements

The exit ramp management system must monitor and manage exit ramp queues on a 24/7 basis to prevent or minimise interference with mainline traffic flow.

4.5.1.2 Operational policy

As traffic demand increases, the policy for exit ramp management is as follows:

- As the exit ramp demand increases, the ramp is given progressive priority at the surface road intersection (i.e. sign controller allocates increasing green time to the ramp departure movements). This may also require alteration of phasing of adjoining signalised intersections to ensure that movement progression along the surface road is maintained;
- If queue spillback at an intersection downstream of the ramp is blocking the surface road such that vehicles on the exit ramp are unable to enter, then signal control techniques such as gating may be implemented. For example, gating at the ramp intersection to reduce green time for the surface road through movement and re-allocate to the ramp departure movement; and
- If surface road traffic control strategies cannot manage ramp queues within the exit ramp storage, then mitigation strategies should be applied. This may include use of mainline VMS to encourage motorway traffic to use other exits as well as dynamic lane management strategies (where ALR and/or LUMS is installed). For example, allowing use of the emergency lane by exiting traffic to prevent exit ramp queues from blocking the mainline flow, or dedicating the left lane approaching the exit ramp to exiting vehicles only during peak periods (this will help to separate exiting vehicles from those progressing on the mainline and therefore reduce turbulence near the exit ramp diverge). Mainline VSL may also be required to provide back-of-queue protection.
- Note: Priority consideration needs to be given to bus services as they need to be serviced in a reasonable time and their schedules means that they cannot be easily rerouted to other routes.

4.5.1.3 High-level technical requirements

The high-level technical requirements for exit ramp management are still in development. The key additional requirements to mainline systems relate to coverage of CCTV and vehicle detectors to extend to exit ramps and surface road intersection/approaches, as well integration between the arterial road signal control system (SCATS) and the motorway control system (STREAMS) that manages traffic speed and lane use and provision of traveller information.

4.5.2 Wide area network dispersion (WAND)

WAND is a network optimisation strategy that supports motorway evacuation and wide area traffic dispersion/re-routing following a major incident or severe congestion event on the motorway mainline or to support evacuations of a region due to a major disaster or security issue. The strategy utilises VMS and LUMS located on the mainline upstream of the site, as well as surface road VMS and third party traveller information services reaching motorists across the network so as to encourage alternative route choices.

Previously, LUMS and VMS have been implemented to manage traffic at a localised level relative to the section of network where the problem has occurred. The new strategy utilises LUMS and VMS across the Melbourne motorway and surface road network, as well as third party traveller information services, so as to provide a coordinated, network-wide response to an incident or event. Such a strategy will be able to better influence alternative route choice and manage travel demand during an incident in order to minimise localised congestion issues.

In the future these information services may also be integrated with information for other transport modes to offer a truly multi-modal response and reduce traffic on the network when there is a severe capacity restriction.

The strategy is still in development and hence only limited information is available regarding system requirements. These requirements may evolve to encompass multi-modal strategies such as maintaining priority for on-road public transport services such as DART (Doncaster Area Rapid Transport) bus service.

4.5.2.1 High-level functional requirements

The WAND system must provide advanced diversion and re-routing of traffic across the Melbourne road network during a major incident or severe congestion event on a motorway in order to:

- Support closure of motorway lanes or full carriageway upstream of a major incident/event;
- Minimise the propagation of congestion on the motorway and connecting surface road network and thereby reduce delays for road users;
- Prevent travellers being trapped on congested/blocked motorways; and
- Keep travellers informed and encourage alternative route and mode choices.

4.5.2.2 Operational policy

Following the detection and verification of a major incident, the operational policy for WAND is as follows:

- As early as possible, provide advance warning to road users of the location, cause and impact of the incident to enable informed travel decisions. Advance warning should be provided by both VMS and third party traveller information services that can be delivered in-vehicle, and should be considered both in terms of timeliness of response and the distance from the effected motorway section;
- Where LUMS is available, progressively close lanes upstream of the incident site to divert traffic on the mainline off multiple upstream exits or on to alternative motorway routes where suitable routes are available. The requirements and sequence of lane closures will be determined by the severity and impact of the incident (e.g. single lane versus full carriageway closure), the LUMS operating rules and the layout of exit ramps and LUMS gantries;
- Operate motorway interchanges and connecting arterials to prioritise dispersion of traffic away from the motorway network (refer to exit ramp management – Section 4.5.1) and to restrict vehicles from entering the motorway (refer to entry ramp management – Section 4.3.2); and
- If LUMS is not available, then VMS can be used to display diversion messages for upstream exits; and
- WAND should be operated to progressively take more severe action as problems get worse. For example, more advanced warning and diversion from the motorway mainline.

An arterial road management system extends the WAND principles to take a truly network-wide response to managing severe motorway incidents and events, as described in Section 4.3.3.4.

4.5.2.3 High-level technical requirements

The high-level technical requirements for WAND are still in development. The requirements for the mainline tools (refer to Section 4.4) are generally relevant, and in addition WAND would require that:

- VMS are located appropriately at strategic locations on surface road network; and
- WAND rules/operating principles are incorporated to the automatic LUMS response (i.e. part of the LUMS Rules Engine) to ensure WAND is implemented in coordination with other control intervention and optimisation strategies.

LUMS is able to generate and publicise real-time incident information in a standardised format for dissemination via the media and third party traveller information services.

4.5.3 End-of-motorway management

Operational issues may be experienced at the end of a motorway due to the limited capacity of the surface road network to carry high traffic inflows from the motorway. End-of-motorway management is critical to minimise the occurrence of traffic backing up on the motorway and causing major congestion that may block upstream entry and exit ramps.

The types of tools and operational strategies that may be used include (Austroads 2014):

- Use of lane pavement markings, static signage and LUMS to facilitate segregation of flows using the last exit ramp with flows continuing to the end of the motorway;
- Pre-emption of signals on connecting surface network to maximise motorway outflow;
- Signalisation of entry ramps upstream of motorway exit as form of gating to hold back traffic approaching the end of the motorway and encourage rerouting;
- Re-routing motorway traffic using mainline and surface road VMS, as well as adjustment of traffic signal operations on connecting surface road network at upstream entries/exits; and
- Use of mainline VSL to provide back-of-queue protection.

VicRoads' operational policies and requirements for this strategy are in development.

4.5.4 Vehicle detectors

4.5.4.1 High-level functional requirements

Vehicle detectors must provide real-time and high-quality/ accurate traffic data that enables:

- Exit ramp queue management (refer to Section 4.5.1) and end-of-motorway management (refer to Section 4.5.3), including operational tuning of algorithms and monitoring of performance;
- Calculation of travel times for display on mainline and surface road VMS; and
- Timely and reliable detection of incidents and congestion, as required for AID and queue detection/queue protection algorithms.

4.5.4.2 High-level technical requirements

Detailed requirements for vehicle detectors to support management of traffic exiting the motorway will be identified as part of further development of the operational strategies outlined in Section 4.5.4.2. Generally the same principles will apply in terms of data quality, timeliness and accuracy as outlined for entry ramp management (refer to Table 4.7) and therefore the detailed technical requirements outlined in Section 8 also apply. An additional requirement currently identified to support exit ramp and surface road interface management included in Table 4.16.

It is assumed that stop line detectors are provided as part of the arterial road control system (SCATS).

Table 4.16 High-level technical requirements for vehicle detectors to support exit ramp and arterial road interface management

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.5.4.1	Installation of detectors on the exit ramp and mainline to provide SVO data that can support operation of the exit ramp and arterial road interface algorithms. This includes measurement of queue lengths on ramps, either through algorithm analysis of detectors or direct measurement, as well as on the motorway mainline on approach to exits.	N/A

4.5.4.3 Potential future developments

Future developments will be closely linked to exit ramp management outlined in Section 4.5.1.

4.5.5 CCTV

4.5.5.1 High-level functional requirements

CCTV must enable real-time monitoring and verification of network conditions to support:

- Timely detection of incidents, congestion and weather events;
- LUMS operation and management of congestion and incidents;
- Exit ramp management tuning and optimisation; and
- Other operational functions.

4.5.5.2 High-level technical requirements

The high-level technical requirements for CCTV operation are the same as outlined in Table 4.8 (Section 4.3.7) with the following addition in Table 4.17.

Table 4.17 High-level technical requirements for CCTV to support exit ramp management

ID	High-Level Technical Requirements	Cross-References to Existing VicRoads Guidelines
4.5.5.1	Full coverage must be provided of exit ramps, including the surface road intersection approaches/departures and areas of potential queuing on the motorway mainline.	N/A

4.5.5.3 Potential future developments

Potential future developments are the same as those outlined in Section 4.3.7.

4.6 Managing the wider road network

It has become increasingly apparent that there is need to understand the real time performance of our broader metropolitan road network (inclusive of freeway and arterials roads) to enable VicRoads to make both strategic and tactical decisions on how the network should be best managed and operated under normal day-to-day demands and patterns and during major events or incidents causing significant network disruptions. In order to do this we need to develop a series of real-time network tools that can provide the following functions:

- Understanding the entire surface road network traffic state in real-time including understanding of generalised traffic patterns of congestion/demands and seasonal changes;
- The capacity of each link in the road network needs to be known and should be categorised as being in either a stable (within capacity) or unstable (oversaturated) state with the clear identification of the location of fixed bottlenecks (i.e. recurrent capacity constraints) and temporal bottlenecks (i.e. unusual or incident based congestion leading to loss of network capacity and grid-locking of network). This needs to recognise step changes in capacity/ lane availability in time based on opening/closing/changing of lane use, including modal priority;
- The ability for the system to monitor network performance (e.g. delays, travel times etc.) on conflicting links and enable localised and broader network optimisation of intersection operations with the understanding of the surrounding network and its capability to cater for operational changes;
- The ability for the system to automatically identify and flag to operators when the network performance departs sufficiently from generalised patterns which may indicate the presence of a significant capacity constraining incident or event;
- The ability of the system to recommend potential control and scope of communication responses to an identified network event(s). Multiple response scenarios would be generated, ranked and recommended requiring road operators to select and implement a response based on a combination of likely modelled outcomes and road operators' previous experience and network understanding;
- Tools to enable operators to quickly identify and assess the significance of identified changes in patterns at the network level resulting from incidents and other demand changes. For example, easily classify major incident events and the extent of their impact, as well as identify alternative detour routes that have spare capacity or routes which can better handle the issue that at hand. (Note that alternative routes may not have the spare capacity that may be desirable but will need to be included in route alternatives anyway);
- The ability for road operators to manually identify or define network events to be considered in the system generated response recommendations;
- Ability to identify when the impacts of an event have sufficiently reduced in order to deactivate or appropriately modify active response plans;
- Visualising the status of the network in real time to enable more informed communications with motorists. For example, rather than saying on the radio messages such as 'avoid Montague Street on ramp', the messaging might tell motorists to avoid three particular suburbs, or stay five kilometres away from the CBD, or try city bypass routes etc.

Recurrent system bottlenecks data should form the basis for identifying and prioritising road and operations improvements projects and the economic cost of recurrent system as well as temporal bottlenecks should be automatically calculable from the network data.

Strategies and tactics would need developed to provide whole-of-network outcomes on how to best manage temporal bottlenecks at the network level. For example, by developing more refined and assistive diversions techniques that encourage motorists to delay or alter their travel route by offering solutions that disperse traffic onto multiple alternative detour routes rather than concentrating traffic on a few routes closer to the problem, which may result in unnecessary disruption to entire suburbs and grid-locking other roads as well.

VicRoads may in future consider the development of a wider arterial road management system (ARMS) that will deliver the functions listed above and be integrated with the motorway management systems.

4.7 Bringing the tools together

Sections 4.3, 4.4 and 4.5 covered the areas where Managed Motorways tools can be applied - at entries, on the mainline and at exits. The full benefit of Managed Motorways is only achieved by these tools being used together to manage the motorway route and to manage that motorway route within a corridor and network setting. The right combination of tools for a particular motorway will depend on the demands and capacity of that motorway section and its role within the network.

The operation of all Managed Motorways tools as part of an integrated motorway management system with a single operating platform and user interface is covered in more detail in Section 5, along with the driver perspective of how the complete Managed Motorways toolkit appears on the road.

4.7.1 Managing the motorway route

Managing motorways as routes is particularly important for the optimisation levels of active management. The optimisation of a route is achieved through continuous and automated fine-level adjustments to tune performance of that route towards a defined objective target. For route optimisation to be fully effective it must cover the full length of logical routes. In some cases there will be a number of logical routes on a road, however in other cases logical routes can be very long and cross jurisdictional boundaries.

Effective management of motorway routes is therefore dependent on both:

- The available Managed Motorways tools being used together in a carefully coordinated approach to get the best from that motorway; and
- The motorway being managed as a single route even where that route crosses jurisdictional boundaries.

In the future it may also require consideration of how to best manage demand to and from the motorway along a route by proactively opening and closing entry and exit ramps where that will result in a positive net benefit to the motorway and surface road system.

4.7.2 Managing multiple motorway routes

Melbourne's motorway network now comprises interconnected freeway routes, with some sections managed by private road operators. Getting the best performance outcomes for road users from this network of motorways requires decisions to be made at the network level so that the actions by individual operators work to achieve network outcomes. Coordination at the motorway network level needs to include information to travellers, interventions to change network characteristics, optimisation of traffic flow and demand management measures such as pricing. At the local level, the traffic management approaches on intersecting motorway routes must be coordinated to allow safe and efficient operation of both routes and to provide consistent instructions and advice to motorists.

4.7.3 Integrated corridor and network management

Integrated Network Management is required to manage the interconnected routes that now form Melbourne's motorway network and work together with surface roads and off-road public transport facilities to form Melbourne's transport network. The required approach is likely to be a part of the active management level described as multi-modal network management, with initially the focus on managing multiple interconnected motorways in advance of applying the optimisation to the entire road network.

Integrated Network Management requires the establishment of operational protocols covering how routes will be managed to achieve network outcomes for safe, reliable and efficient operation and to satisfy the Managed Motorways policy objectives and principles. Coordinating traveller information, traffic management interventions and optimising routes and networks will require increasing levels of system integration to allow real-time adjustments with minimal human intervention.

As the state road authority with responsibility to the community for transport outcomes that depend on the whole road network, VicRoads has a critical role to play in Integrated Network Management. As the network operator, VicRoads retains the overriding authority on operational protocols to achieve network outcomes. Similarly, in integrating systems to enable these network outcomes, the Traffic Operating Software of the State (TOSS) is the central point of coordination and has precedence over any systems that must integrate with it.

4.8 Multiple road operators

Selected portions of the freeway network in Melbourne are operated by other road operators. At present, these selected segments include CityLink, EastLink and Peninsula Link. Where another road operator has responsibility for operating a road network, they have usually deployed a separate system to provide the required operational functions.

The emergence of the more advanced freeway operational functions in the last few years, however, now presents a challenge as to how these new advanced functions shall be provided on private road segments and how these road segments will participate in the emerging 'whole of network management' approach being implemented by VicRoads.

4.8.1 Formal coordination of operations between road operators

The introduction of Managed Motorways operations since 2009 has changed VicRoads approach to motorway management as both traffic control and operations are no longer captive to short sections of freeways as the new motorway tools such as LUMS, VMS (traveller information), and coordinated ramp metering now operate network wide with traffic control and traffic information operating seamlessly between different freeways and along entire freeways.

Melbourne has a large network (some 300 km) of urban freeways and their operation and optimisation relies heavily on this network wide approach to maximise traffic flows and managing incidents across the entire freeway network. An incident may require motorway management systems to reconfigure the network over many kilometres. For example, a closure of the Burnley Tunnel may require LUMS/VSL, CRS and VMS systems to automatically configure the network over many kilometres away from the tunnel closure, even as far out as Springvale Road or further with VicRoads travel time (DriveTime) information. Changes to lane availability and speed limits in motorway operations may also change the roads' capacity and hence the CRS system need to be integrated with these other freeway tools to ensure smooth operations across Melbourne throughout these major events.

VicRoads' role as the central point for road operational policy is recognised in the Transport Integration Act (2010), with its functions including to develop and implement operational policies and plans, including through legislation, regulations, standards, guidelines and practices, for the road system and related matters consistent with the strategic policies and plans of the Department (Section 87, Clause 1e). This function as the standard setting organisation is strengthened by VicRoads' role as the central issuer of approvals for 'major traffic control' items, including traffic signals and speed limits.

This function and role means that the development of agreed Operational Protocols between road authorities involved in Melbourne's road network must involve the relevant parties but can only logically be led by VicRoads. Similarly, where disagreement arises between road operators in the development and implementation of such Operational Protocols, the final decision logically rests with VicRoads to the extent that various enabling acts for other road authorities' permits.

4.8.1.1 Key aspects of VicRoads' operational approach

VicRoads' Coordinated Ramp Signalling (CRS) system is recognised internationally as world leading due to Australia's unique approach to real time optimisation using leading control technologies. Whilst there are many different types of ramp metering systems in use round the world, VicRoads has not identified a superior alternative to the HERO LIVE Coordinated Ramp Signals System which was progressively developed over 28 years by the Technical University of Crete and co-developed for field operations with VicRoads over the past seven years.

The Intellectual Property (IP) behind HERO LIVE and the rules engine used for LUMS are tightly controlled. VicRoads as co-developer of HERO LIVE since 2007 has retained the rights to use HERO LIVE algorithms for the State of Victoria for a very small once off fee for every new ramp meter added to Victoria. VicRoads likewise has continued access to the IP required for LUMS. Other road operators have access to this IP from the system suppliers on a normal commercial basis through the STREAMS product.

4.8.1.2 Consideration of specialised requirements for tunnel management

VicRoads does not currently manage any road tunnels and accordingly has not developed procedures or procured systems for tunnel management. Tunnel management introduces requirements for fire safety and air quality management that are not present in open road environments. Many systems used for tunnel management provide some traffic management functions in addition to the functions for fire safety and air quality management and there is some dependence on traffic management responses to achieve the required fire safety and air quality management responses.

When road tunnels were first introduced to Melbourne they operated generally on a standalone basis as there were no route based lane and speed control systems with which the traffic management systems in the tunnels for lane and speed control were required to interact. This situation changed with the M1 Upgrade and the installation of LUMS and CRS along the M1 route. Arrangements were made as part of the M1 Upgrade to achieve the necessary operational and system integration to manage this situation, but the overall role of tunnel traffic management systems within a route and network was not reconsidered at that time.

4.8.1.3 Limitations of the current approach

To demonstrate the need for a different approach, it is necessary to highlight some deficiencies in the current practice of operating the VicRoads and Transurban systems on the M1. These are:

- Changes to the State policies need to be reflected in multiple systems e.g. adopting flashing red cross or white arrow;
- New or enhanced traffic management tools and rules can be difficult to deploy across the network (e.g. in relation to LUMS, CRS and dynamic speed management), as development is required in both systems;
- There is no opportunity to share enhancement costs across all road operators;
- Non-uniformity in the application of rules and therefore traffic responses are leading to inconsistencies from a road users point of view;
- Considerable differences to incident management approaches, for example VicRoads using a rules based (automatic) approach and Transurban using predefined traffic plans (manual/labour intensive), lead delayed implementation of responses and issues across boundaries;
- Separate systems cannot prioritise responses to multiple simultaneous incidents;
- Limited ability to view each other's ITS devices e.g. status of VMS to ensure appropriate messaging is displayed to road users for consistency along a route;
- Some limitations to CCTV access for rapid verification of incidents;
- The significant cost and complexity associated with developing a system-to-system interface has been resource intensive and a prolonged implementation delayed its introduction for operators;
- The system-to-system interface dilutes ownership of operational faults and can result in transferring of responsibilities.

4.8.2 System-to-system context

The current generic system-to-system architecture is as shown in Figure 4.2. While the private road operators have implemented many of the standard roadside ITS equipment (i.e. vehicle detectors, CCTV, VMS, ramp signals and LUMS), none of the central systems of the private road operators have implemented the more advanced Managed Motorways functionality described in the preceding chapters.

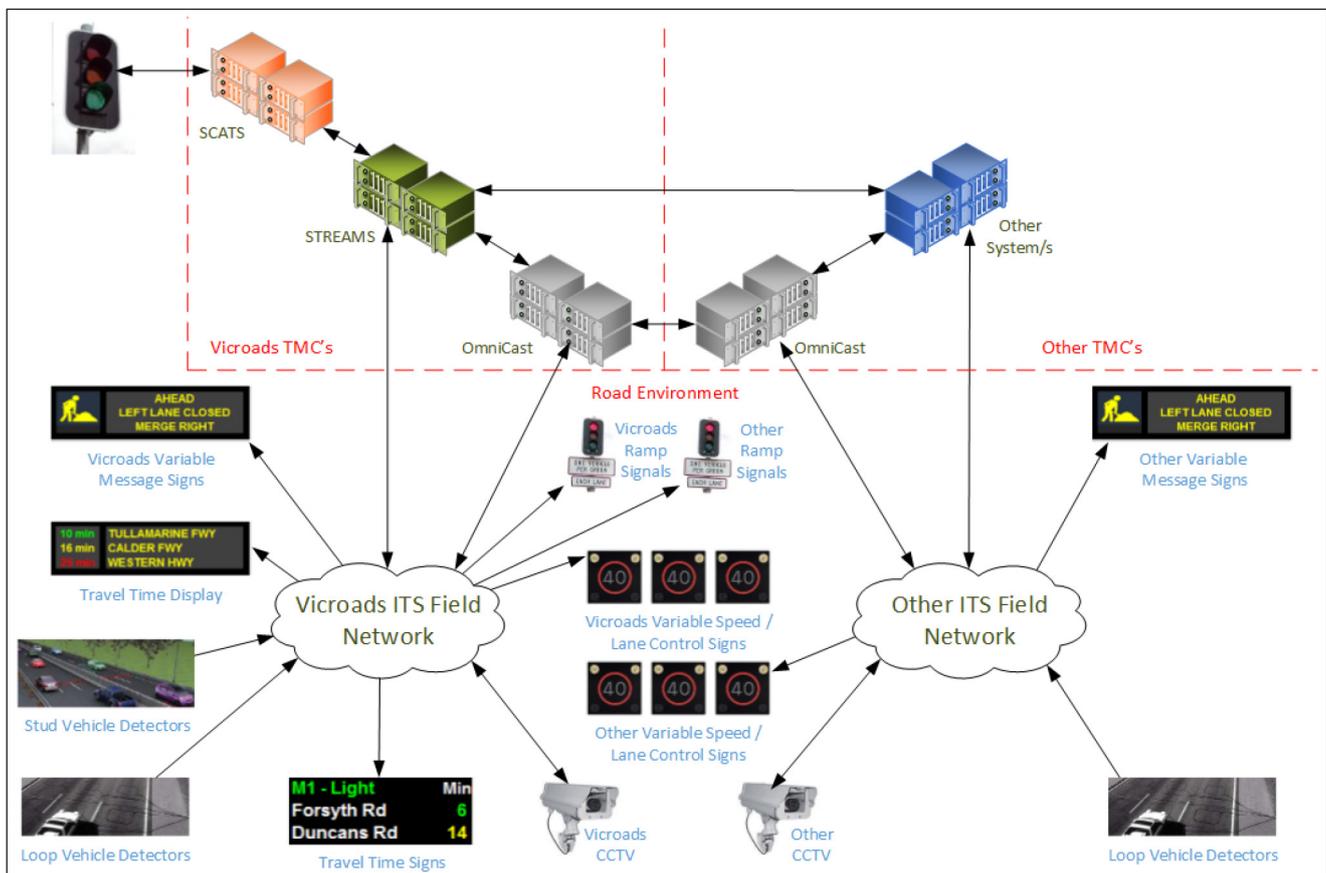


Figure 4.2 Current generic system-to-system architecture

There are a number of instances where the prior implementation of a specific system by VicRoads has resulted in a specific standard and architecture being adopted which has had implications for private road operators. These systems and their associated implications are listed below:

- **SCATS traffic signal management.** VicRoads chose SCATS for its traffic signal management functions over 30 years ago and has built up a significant level of expertise in it. Most controlled intersections do not operate in isolation and must be coordinated with other adjacent intersections. For this reason, all new intersections must be connected to the VicRoads SCATS system, even if they are part of the private road infrastructure.
- **Omnicast CCTV control and management.** VicRoads chose Omnicast to manage the control of CCTV and distribution of video across the VicRoads ITS network. While it is theoretically possible to interconnect with other video management systems, to do so can incur a significant reduction in performance of camera control, real-time video distribution and the management of security in relation to video management. For this reason, it is recommended that all new CCTV infrastructure use Omnicast as the platform of choice. This enables an Omnicast installation used by a private roads operator to be federated with the VicRoads system, allowing secure bi-directional viewing and control of CCTV across the whole road network.
- **Coordinated ramp signals.** VicRoads chose the ALINEA/HERO algorithms to manage ramp meters across its motorway network. It is frequently a requirement for the management of a freeway bottleneck to request a reduction in the incoming flow of more than one entry ramp in order to prevent flow breakdown. The logic for this function exists in the VicRoads STREAMS system and significant complexity would arise if an attempt was made to distribute this logic across multiple central systems. This approach would not add any new operational functionality or benefits, but would increase system response times, decrease tool chain reliability and create additional complex logic to ensure that the ramps work together co-operatively. For this reason, all ramp signals are connected to and operated by the VicRoads STREAMS system.

4.8.2.1 Required system architecture

In planning the addition of future ITS functionality, it is important to understand that the architecture chosen to deliver a feature can simplify or complicate the resulting systems. ITS systems already require many interfaces between different equipment and computer types. As can be seen from the previous examples, keeping the systems architecture simple can often produce the best, most reliable and cost-effective outcomes.

Interfaces between components of a system allow the easy flow of information through the tool chain. Where they are also used to provide control, additional care must be exercised to ensure that each interface does not introduce complexity that threatens the outcomes that are trying to be achieved. Examples of potential threats include:

- **Delays in response time.** Each new interface will add more delay to the data collection and control coordination functions. Too much delay in responding to changing traffic conditions could prevent desired benefits from being realised. For example, if the CRS system was too slow to respond to a rapid increase in freeway density, flow breakdown would occur which may not recover until after the peak has finished.
- **Decrease in reliability/availability.** Each new interface introduces more potential points of failure in the tool chain. No software, hardware or network has 100% reliability/availability, so the introduction of new equipment can only decrease reliability/availability.
- **Complexity in coordination.** Where a control strategy requires multiple devices to coordinate to achieve a desired outcome, the addition of new interfaces can add complexity to the control environment. Many of these control requests are 'all or nothing' - in that you want all required devices to work together and if this is not possible, then a different control request will be used. This requires more complex interactions between systems to achieve and increases the potential for fragmentation of control requests in the field.

Although it is theoretically possible for interfaces between multiple systems to provide the necessary shared management and control of a route, this is particularly challenging where tighter integration is required for optimisation control along a route, rather than the more common requirement for intervention control and traveller information to pass through system-to-system interfaces. The requirement for optimisation control across multiple road operators as part of Melbourne's motorway network is what triggers a requirement for the Traffic Operating Software of the State (TOSS) to be the central point of coordination and have precedence over any systems that must integrate with it.

Further detail regarding the required future architecture and performance requirements for a system-to-system interface for VicRoads and other road operators is provided in Section 7, particularly Section 7.6.

Section 5

Summary - Human Machine Interfaces (HMIs)

Managed Motorways strive to maximise use of automated ITS services to improve operational efficiency and involves a complex system of business processes and data flows. Nevertheless, the systems inevitably have to interact with humans throughout their operation, including both road operators and road users, and understanding how to improve the nature of these interactions is critical to success.

The Traffic Operating Software of the State provides a graphical user interface with multiple viewpoints to serve different user needs and functions. These include a schematic-based view, a map-based view, a list-based view, system configuration and motorway reporting. The value of these different views to operators is the ability to visualise the current operation of the network as a whole while also receiving alerts and information about the status of individual ITS devices and network conditions.

From a road user perspective, a Managed Motorway needs to be a self-explaining driving environment that exerts simple controls and information to road users that they can directly associate with improvements to their journey. Driver behavioural response and compliance is key to the effectiveness of the enabling technologies, and human factors must be therefore considered in design and operations. Consistency and reliability of traffic control and information across the network, including across operational boundaries, will help to improve driver perceptions and compliance. The emerging layers of active management will add new road user interactions that must be managed carefully.

This section further explores the types of road operator and road user interactions with the Managed Motorways system.



5. Human Machine Interfaces (HMIs)

Although much of the operation of systems to actively manage motorways is automated, understanding how these systems interact with humans is critical to their success. Two main interactions will be explored here:

- Section 5.1 covers the use of the system by a road operator; and
- Section 5.2 covers the use of a Managed Motorway by a road user.

5.1 Road operator interface (real-time GUI)

Even with the increasing use of automation in motorway optimisation, road operators play a critical role in the active management of Melbourne's motorway network. The Road Operator Interface (or graphical user interface – GUI) is the HMI used by operators and others to monitor and control the Managed Motorway. This HMI must assist the operator to understand the situation and make and implement good decisions, all in an environment of increasing complexity.

To assist this, the interface for the Traffic Operating Software of the State (TOSS) provides multiple ways of viewing current status and configuring system operation, each designed to meet particular needs. These include:

- Schematic-based view
- Map-based view
- List-based view
- System configuration
- Motorway reporting.

These are described in the following sections. General requirements for the operator interface include:

- Appropriately short load time of software used for monitoring and control;
- Appropriately short response time to changes in field equipment status being updated in the display; and
- Appropriately short response time to changes in system configuration being implemented.

5.1.1 Schematic-based view

The Managed Motorways schematic is the primary means of monitoring and controlling the status of electronic signals and signs used for LUMS, VSL, CRS and roadside traveller information, as well as supporting ITS equipment. A key advantage of the schematic is that the display that shows both a network view, to provide the network context, as well as freeway operation on a lane-by-lane basis. It can also display a non-proportional representation of the motorway, producing a more user-friendly display than the equivalent map (refer to Figure 5.1).

The Managed Motorways schematic capability must support the following features:

- Facilities to import and animate road network schematic backgrounds;
- Able to display a single schematic covering the whole VicRoads Managed Motorways network;
- Able to support multiple smaller schematics to display individual sections of the network;
- Provide navigation aids to move around the schematic that include zoom in/out, pan, scroll and mini-map;
- Able to launch a schematic from a list or map view icon menu of any device on that schematic;
- Able to support both display-only and control modes, depending on user permissions;
- Provides the ability to display the current status of all motorway equipment in real-time, including:
 - Variable speed limit and lane control sign displays on a lane-by-lane basis
 - Ramp signal controllers and associated RC1, RC2 and RC3 signs
 - Vehicle detectors on a lane by lane basis (STREAMS 2014.1 and later)
 - Variable Message Signs (VMS) and Changeable Message Signs (CMS) message displays
 - CCTV locations (with pop-up image viewing & control)
 - Arterial traffic signal status
 - Other devices that may be installed for weather monitoring or automatic incident detection.

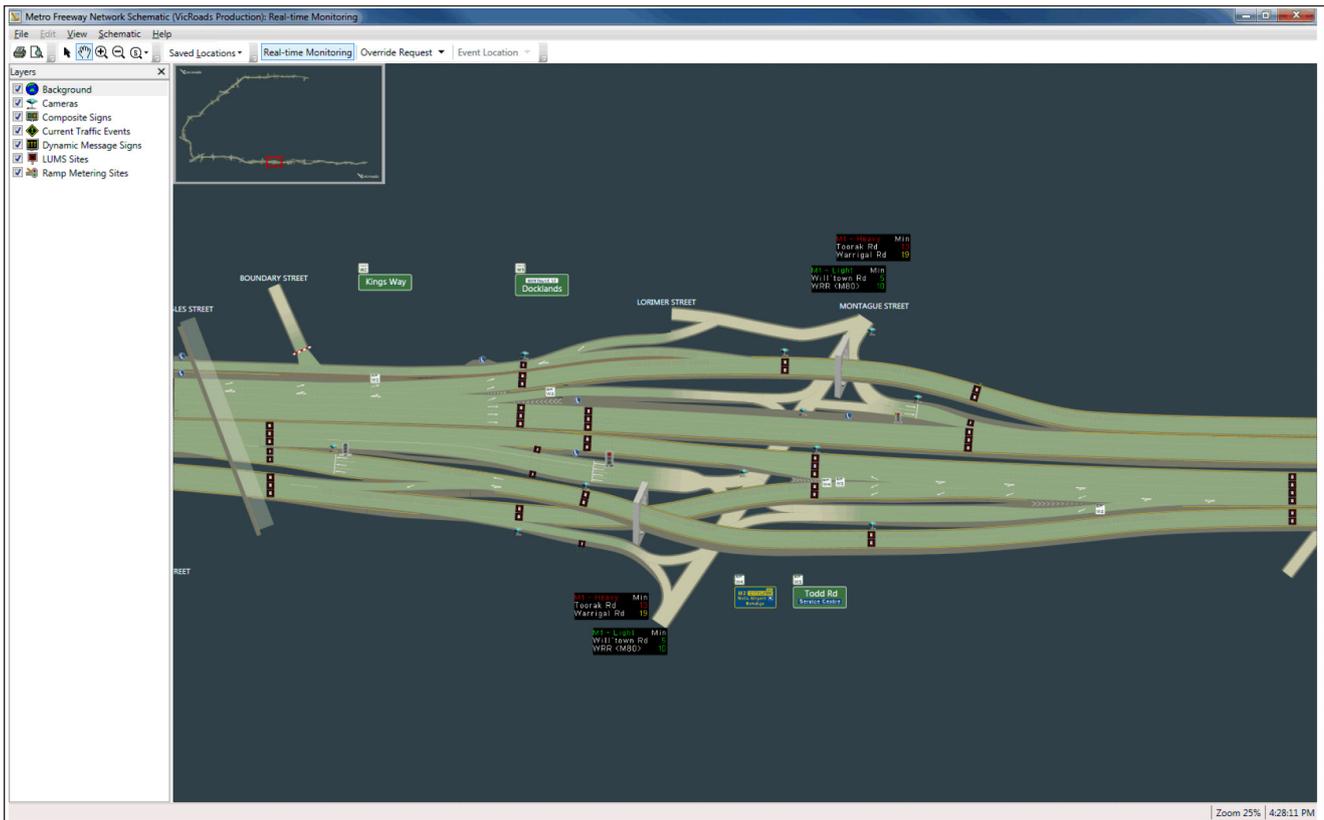


Figure 5.1 Example of current VicRoads schematic

Where user permissions allow, the schematic provides the operator with the ability to request speed limit and/or lane control changes. Before implementation, the schematic displays the requested changes merged with any pre-existing control changes and any other LUMS changes to implement the required speed buffers, lane closure tapers and speed change smoothing.

5.1.2 Map-based view

The map-based view overlays the dynamic equipment on a map of the road network and colours the roads to show current traffic conditions. The key advantage of a map-based view of the Managed Motorway is that it can show the traffic conditions on adjacent or connecting corridors.

The Managed Motorways map view capability must support the following features:

- Facilities to import a baseline map and build a movement-based transport network model that includes all ITS equipment into the system;
- Provide navigation aids to move around the map that include zoom in/out, pan, scroll and favourites;
- Able to select which devices are shown on the map, subject to user permissions;
- Provide the ability to display the current status of all motorway equipment in real time, including:
 - Vehicle detector data shown as coloured road links reflecting current conditions
 - Pop-up displays of variable speed limit and lane control sign messages
 - Pop-up displays of ramp signal controllers, including state of ramp signs (RC1 and RC2)
 - Variable Message Signs (VMS) and Changeable Message Signs (CMS) message displays
 - Pop-up displays of CCTV images (with optional control)
 - Pop-up displays of alerts for other devices that may be installed for weather monitoring or automatic incident detection; and
- Provide the ability to launch an appropriate schematic.

5.1.3 List-based view

The list-based view provides lists of dynamic equipment, listing to show current traffic conditions. The key advantage of a list-based view of ITS devices is that it can quickly show a summary of equipment status.

The Managed Motorways list view must support the following features:

- Provide the ability to show both specified and current status information for each device;
- Provide the ability to sort and filter each list view;
- Provide the ability to jump to the map view showing a device;
- Provide the ability to launch an appropriate schematic associated with a device; and
- Provide the ability to show (and subject to user permissions, change) properties of ITS devices.

5.1.4 System configuration

The system configuration software allows traffic engineers to monitor and configure the operation of the system and, in particular, the automated algorithms. All critical settings for the operational algorithms should be available for operator review and modification where required.

5.1.5 Motorway performance reporting

Performance reporting is critical to checking the performance of the motorway and the impact of changes made to operations.

The Managed Motorways performance reporting must support the following features:

- Provide reports including the following:
 - Current motorway performance reporting (e.g. speed, flow, density, reliability etc.)
 - Historical data entry report
 - Historical motorway performance report; and
- Support appropriate retention of historical data to meet operational and legislative requirements, including system performance

5.2 Road user interface

Active management of freeways involves systems of substantial complexity and operational and optimisation business processes, but which ultimately achieve the management of traffic flows through deliberately simple interactions with the drivers of vehicles on and around the motorway. The most capable active management systems are only as effective as the responses they elicit from those drivers, and so the human behaviour aspect of traffic engineering must be part of designing and operating Managed Motorways.

The simple interactions with road users mask the complexity behind the scenes. For example, a road user sees only short but variable cycles for green lights at ramp signals, not the calculations behind this that update signal timings every 20 seconds based on conditions right along the motorway route and its entry ramps. In many cases, the safety consequences of not complying with ramp signals are not severe; think of the difference of running a red light at an intersection compared to a ramp signal where you simply arrive at the merge point a little earlier. An important part of compliance therefore is trust and confidence by road users in the active management systems - we cannot rely on compliance solely on the basis that it is illegal to not comply.

However, compliance with variable speed limits and lane use management systems is of greater importance since non-compliance can directly result in a safety risk. For example, if a driver ignores a lane closed instruction that has been put there because of an accident involving a stationary vehicle on a live running lane, then there may potentially be a secondary accident.

5.2.1 Entering the motorway

In addition to the usual signs and line-marking for traffic management, there is a standard series of interactions with a driver as they move to enter the motorway where that driver is. For example, the driver is:

- 1 Advised of the travel conditions on the motorway or any incidents of importance at a point at which the driver can still decide to not enter the motorway;
- 2 Advised whether ramp signals are active to assist expectations upon entering the ramp;
- 3 Controlled by the traffic signals on the ramp; and
- 4 Advised of the speed limit applicable to the motorway at the merge area.

5.2.2 On the motorway

Once on the motorway, in addition to the usual signs and line-marking for traffic management, the interactions with the driver are through:

- Overhead signs that indicate any lanes closed to traffic or restricted to certain user classes, preceded by instructions on when required to merge out of a closing lane;
- Signs to indicate the current speed limit, often in a form combined with the lane use signs; and
- Supporting messages about current travel times/conditions and/or future events.

Unlike the entry to the motorway where the driver progresses through the four interactions outlined in Section 6.2.1 in a fixed sequence, along the motorway the order of the information may vary such that the driver sees a control restricting speed and/or lane use before they see a variable message sign with information about the reason for the control.

A recent comprehension study in Perth (Boddington et al, 2014) confirmed that even in a city without extensive lane use management, the rate of comprehension by drivers of the Lane Use Management System (LUMS) was very high. The results of this study included a preference by drivers to be better informed about why any restrictions were in place which aligns with findings of the Speed Limit Advisory Group (SLAG) to better explain the reasons that particular speed limits applied. A possible evolution of VicRoads current approach to LUMS would be to include additional and more frequent explanatory messaging than is currently provided, for example placing small (limited purpose tactical) VMS on every second or third gantry.

A second finding of relevance from the Perth study was to do with the implication to road users of a blank sign. One contributor to the current approach in Victoria of displaying speeds on every LUMS sign was feedback from a limited survey that blank signs might be interpreted by road users to mean that there was a sign fault. The encouraging result from the Perth study is that nearly all drivers in this larger survey correctly interpreted the speed limit and lane status at a gantry with blanked signs even without any supporting static signs. There was a slight preference for signs to always operate (56% compared to 44%), however the result opens the possibility of reducing the number of LUMS gantries active during normal (unrestricted) conditions reducing electricity use and increasing sign life. This practice is currently seen in other jurisdictions such as England.

5.2.2.1 Full-time and part-time lane use

Motorway lanes in Melbourne are generally available to traffic on a full-time basis even where there is no emergency stopping lane (referred to as all lane running). The most notable exception to this is on the Eastern Freeway, where the emergency stopping lane is available to certain road user classes including buses on a part-time basis.

The use of full-time all lane running (ALR) significantly streamlines operations not only for road operators, but also for road users. At almost all times, all lanes on the motorway marked as traffic lanes are open to traffic. The main exception to this is clearly signed through the display of a 'red X' above the relevant lane(s). In addition to greater consistency and reduced uncertainty, this approach also significantly simplifies the more traditional traffic management measures such as line-marking around interchanges.

A well-known example of part-time lane operation was the M42 Active Traffic Management pilot near Birmingham in England. Although this pilot was successful, as part of streamlining operations and reducing costs and complexity, the Highways Agency has now transitioned to deploying full-time ALR for new schemes.

5.2.2.2 Using variable speed limits for congestion management

The current use of speed limits on Melbourne's motorways is to maintain the safety of motorway operations at times of changed conditions. There are several reasons to change speed limits for safety, such as for safety at incident sites, to protect the back of queues and during adverse weather. Many of speed limit changes made for such safety reasons are made with only indirect consideration of efficiency impacts, with the primary objective being to maintain safety.

The use of speed limits for congestion prevention and management (as described in Section 4.4.2) is a change to how speed limits are used as in this case while there are still safety benefits, the maintenance of efficient operations is the prime consideration. There are a number of other road rules and operations focussed primarily on efficiency rather than safety, including bus and tram lanes as well as ramp signals. For this reason, it is likely that road users will accept the use of speed limits for efficiency in the same way that these other road operations have also been accepted. Nevertheless, the use of speed limits for congestion prevention and management should recognise the difference to other uses of speed limits and factor this into the compliance and enforcement approach, including ongoing communication with road users.

5.2.3 Exiting the motorway and on the surrounding road network

Upon exiting the motorway, in addition to the usual signs and line-marking for traffic management the most notable interaction with the driver is through the traffic signals generally provided at the ramp terminal. There is little change in this interaction between traditional and actively Managed Motorways, although the traffic signal may be receiving additional information to assist it to manage queues on the exit ramp.

The introduction of any part-time exit queue management approaches, such as using the emergency stopping lane to keep queues away from through traffic, would add a new interaction with the driver.

5.2.4 Traveller information throughout the journey

Information is provided to road users, or at least available to them, both before and throughout their journeys. There are three main sources of benefit from this information:

- Assists transport users to optimise their journeys to meet their needs;
- Assists to reduce demands on sections of the road affected by incidents or unusual delays; and
- Reduces the penalty of uncertainty even in cases where a driver continues on their journey as planned.

The second benefit area provides broader community benefits by allowing more effective use of the available capacity in the transport network; however, it is entirely subject to the choices that transport users make in response to the provided information. Driver surveys conducted as part of congestion management in Melbourne identified a general reluctance to change usual and/or planned trip times and routes even where that trip would be affected by congestion. This reluctance was not universal and in part was attributed to lack of confidence by drivers in the alternatives, suggesting that more targeted information may assist overcome this barrier. Providing targeted information is challenging in mass communication methods, such as radio bulletins and variable message signs, due to the wide variety of potential destinations, therefore the increasing use of more personalised information offers some potential to assist. Personalised information may include information distributed by third party applications that know the users location and intended journey (or are able to predict it based on recorded user preferences and historical use of the network), and therefore can ensure only information relevant to that particular road user's journey is provided.

Table 5.1 summaries how information is provided to travellers on Managed Motorways before and during their journeys.

Table 5.1 Providing information to travellers as part of motorway management

	Description	Method
Pre-trip	Before setting off on their journey, the transport user has the greatest opportunity to change the destination, time, route or mode of their travel to respond to any changed conditions or simply a better journey for their everyday needs.	Radio and internet, increasingly on personal devices for more proactive and personalised traveller information
Before entering the motorway	This is the last chance for a driver to take an alternate route before entering the motorway, assisting to reduce traffic entering the motorway during incidents.	RC3 signs on approach to entry ramps, surface road VMS (also referred to as freeway condition signs) on more distant approaches, radio bulletins, in-car systems
On the motorway	In addition to taking a different exit than originally planned, a driver also needs to know about information that affects their journey even if no route change results.	Mainline variable message signs, radio bulletins, in-car systems

5.2.5 Changes in road user interface for enhanced active management

Despite the complexity behind the scenes in optimising and operating Managed Motorways, the interactions with drivers are generally simple and well-spaced. This is a deliberate approach to manage the motorway in a way that the drivers can safely interact with. With a few exceptions, the implications of more intensive active management with more functionality is that there is increased use of those same simple interactions with road users that are already well-established on Melbourne's motorways.

Dynamic variable speed limits for route and network optimisation is an area where the frequency of interactions with drivers is likely to noticeably increase. There is no new interaction introduced here, but rather a more frequent use of the integrated speed and lane use signs already in place.

A potential new interaction does exist for the use of the emergency stopping lane for queue storage as part of exit ramp management. At the moment there is only a single fixed-time operation of this type in Melbourne, on the Flemington Road exit from Western Link; the exit to Alexandra Parade from the Eastern Freeway has been converted to a full-time three lanes. Given this limited part-time use and the desire to keep interactions with road users as simple as possible, the approach to exit ramp management should consider the use of permanent or full-time approaches where practical.

Similarly, dynamic re-configuration of motorway entry and exit ramps to better manage demand to and from the motorway at all times (refer to Section 4.2 for further description) will lead to more interventions being made through the entry ramp and exit ramp management systems. Drivers will have to get used to the concept that closing ramps may help improve freeway traffic flow and deliver optimal travel conditions for the network, albeit at the expense of restricting local access at some locations.

With further development of arterial road management systems, the main increase in interaction with road users is likely to be through greater provision of traveller information on the roadside (e.g. VMS) and via third party applications.

Section 6

Summary - System performance criteria

This section defines a set of criteria or qualities that can be used to measure the performance of the Managed Motorways system based on the desirable outcomes and requirements from a road operator and road user perspective.

The desirable qualities are that the system is accurate, consistent, coordinated, providing good coverage, efficient, fault tolerant, integrated, real-time, aligned with regulation and enforcement requirements, reliable and maintainable, robust, safe, seamless, secure and timely.

These qualities are intended to be measurable and are used to guide development of detailed performance requirements for each of the Managed Motorways system components as outlined in Section 6. They represent the critical qualities from an operational perspective but do not cover all potential technical requirements for a motorway technology-based system.



6. System performance criteria

This section lists a set of fundamental criteria (qualities) that will be used to describe the desirable attributes of road network operations. The relevant qualities and their definitions are listed in Table 6.1. As with all requirements in this Framework, these requirements below are only a sub-set of the requirements for any technology element in the system, with this sub-set providing the required business functionality to support motorway optimisation and operations.

Table 6.1 Qualities that describe Managed Motorways system performance

Quality	Desired outcome	Road user requirement	Road operator requirement
Accurate	An <i>accurate</i> outcome is one that is free from error or defect. For traffic operations, this implies that the provision of information and control will reflect the current state of the road network.	Data collection and processing produces traveller information and directions that accurately represent the current situation on the road network.	Data collection and processing provides accurate operator understanding of current and expected road network conditions, and enables appropriate automated changes to road network controls and information.
Consistent	A <i>consistent</i> outcome is one that always behaves or happens in a similar way.	The operation and appearance of the road management controls and traveller information should be consistent across the whole road network.	The collection of road network performance information is consistent across the whole network. The implementation of control strategies does not significantly vary across the road network.
Coordinated	A <i>coordinated</i> outcome is one which is organised so that the individual parts will work well together	The operation of the different roadside ITS devices supports a single harmonious strategy that is appropriate for the current road conditions.	Response strategies are implemented across all affected ITS devices within an appropriate time window.
Coverage	<i>Coverage</i> refers to the extent or degree to which something is observed, analysed or reported.	Real-time information is available to travellers about the traffic conditions in all areas of current and proposed travel.	The data collection equipment is located strategically and with sufficient frequency on the road network to detect variations in conditions on different parts of the road network. The control equipment is located at all strategic locations to enable control of the whole road network.
Efficient	An <i>efficient</i> outcome is one that works or operates quickly and effectively in an organised way.	The operation of the road network and traveller information provided enable the road user to minimise the time required for their journey.	Implementation of the optimum control strategy for the road network requires minimum work by the operations staff.
Fault tolerant	A fault tolerant system can be defined as one that is capable of performing at normal levels (or close to it) when a fault occurs. For traffic operations, a fault-tolerant system is one that will lose little or no critical functionality when a single fault occurs.	One or more minor system faults will not cause any gross inaccuracy of traveller information or discernible change to control strategies.	As far as is reasonably possible, normal operations should not be significantly degraded by a single system fault. The impact of a minor fault on the implementation of an existing or new response strategy should be minimal and not prevent the desired operational outcomes being realised.
Integrated	An integrated system can be defined as one where all components combine to provide a harmonious solution. For traffic operations, an integrated system is where the ITS field equipment, networks, computer systems and software operate cohesively together as a single system to provide the essential ITS functions to operate the road network.	The presentation of traveller information should be transparent to any operational boundaries in the road network. Road network management controls form a cohesive response strategy – even when implemented across operational boundaries.	All data collected by the system/s is available to all monitoring and control functions on systems across the road management network. The VicRoads system is to be the central collection point for all real-time data collected by other systems as a single point of truth. Response strategies that span across arterial/freeway networks and/or operational boundaries can be implemented as a single request.

Quality	Desired outcome	Road user requirement	Road operator requirement
Real-time	A <i>real-time</i> system can be defined as one that is 'relating to an analytical or computing device which processes information and outputs results at the same rate at which the original information is presented'. For traffic operations, the exact definition of what 'real-time' means depends on the processing rate of the various road management functions.	The provided roadside and online information reflects the current state of the road ahead, with minimal delay in update the information when conditions change. The control equipment on the freeway responds quickly to changes in traffic conditions in order to provide the safest and most efficient journey.	Data collection and processing to be frequent enough to provide current and relevant traveller information. The control systems ensure minimum time between road network condition changes and appropriate changes to control strategies, even when operating across operational boundaries. To do this, the frequency of new data being made available matches or exceeds the requirements of the monitoring and control functions using the data in real time.
Regulatory and enforceability	The <i>regulatory and enforceability</i> requirements ensure that all traffic controls provided are enforceable in order to establish and maintain an appropriate level of driver compliance.	That all dynamic or static regulatory signage is clear to the motorist and not contradictory.	Facilities exist to support all necessary enforcement activities required to improve compliance.
Reliability and maintenance	<p><i>Reliability</i> is a measure of the percentage of time that the system is available to perform its intended task (except for planned maintenance times). It is frequently expressed as an availability statistic, such a 99.9%.</p> <p>Typical reliability specifications are as follows:</p> <ul style="list-style-type: none"> • 99% ('2 nines') = 3.7 days unplanned downtime per year • 99.9% ('3 nines') = 8.8 hours unplanned downtime per year • 99.99% ('4 nines') = 52.6 minutes unplanned downtime per year • 99.999% ('6 nines') = 5.3 minutes unplanned downtime per year • 99.9999% ('7 nines') = 32 seconds unplanned downtime per year <p>The reliability of a system is calculated by multiplying the reliability of each component of the tool chain.</p> <p>Maintenance requirements define the response time required for equipment repairs in order to help achieve the reliability requirement.</p>	<p>The road user should be able to rely on the available traveller information sources to advise of any disruptions that may impact their journey. If directly affected by a new disruption, the guidance given should provide the safest and most efficient means to continue the journey.</p> <p>The road user should be able to rely on the road network controls provided to manage their trip to provide the safest and most efficient journey.</p>	<p>The tool chain that provides road network management/control should be available whenever control is required.</p> <p>Appropriate repair response times are included in all equipment specifications and maintenance contracts.</p>
Robust	A <i>robust</i> system can be defined as one that is strong. It has a low risk of not performing at full capacity. For traffic operations, this means that it is a system with an acceptably low probability of failure that will cause loss of functionality.	Traveller information and optimised motorway control always will be operational during critical periods except during extreme circumstances.	The arterial and motorway control system and interfaces will be fully operational when needed. The design should include appropriate redundancy to prevent single failures from causing a major loss of functionality or coverage
Safe	A <i>safe</i> system can be defined as one that is 'cautious in avoiding danger'. While absolute safety cannot be guaranteed in any road environment, the implementation of ITS can improve the safety of a road.	If the travellers comply with the control strategies implemented, their journey through the road network will be safer than if no ITS was provided.	

Quality	Desired outcome	Road user requirement	Road operator requirement
Seamless	A <i>seamless</i> system can be defined as one that is continuous, with no apparent interruptions. For traffic operations, a seamless outcome would be said to be one where the operation of adjacent sections of the network shows no difference or inconsistency that is apparent to the road user.	<p>Traveller information display should not be observably different to the road user across operational zones.</p> <p>As far as is reasonably possible, control strategies will appear to the road user as if managed by a single road operator/system, even if more than one is involved.</p>	<p>Data collection sub-system/s should ensure that all data required is available across all monitoring and control systems. The monitoring and control processes should transparently use data from any data collection sub-system.</p> <p>The implementation of control strategies across an area controlled by more than one road authority shall be implemented as effectively as if there was one road operator/system</p>
Secure	A <i>secure</i> system is one that is appropriately protected against the risk of unauthorised use of the system's resources.	The road user's trust in the controls and information given to them by the system should never be eroded by the presentation of any unauthorised control or distribution of unauthorised information. The collection of and access to road user information (e.g. for incident management) complies with the state's privacy legislation.	The operation of all components of the system should be unaffected by any attempt to modify or interrupt normal operation of the system. Where equipment is installed in a roadside environment, the selected equipment and manner of installation should minimise the risk of interference with normal operations. Access to data and device control is restricted to authorised users.
Timely	A <i>timely</i> system can be defined as one that provides a service at a suitable time and place. For traffic operations, a timely system is one that quickly changes control in response to changed traffic conditions, advises travellers of changes to traffic conditions promptly and makes that information available at appropriate decision points before or during a trip.	<p>The system provides traveller information to the motorist at a suitable time and location in their journey to support their driving choices.</p> <p>Collected data is distributed promptly to all dependent processes to produce timely traveller information and reduce the delay between changes to traffic conditions and automated system responses to those changes.</p>	<p>Data collection and distribution provides the required data to all dependent systems to minimise delay in monitoring and control functions. This allows the arterial and freeway controls to change quickly to respond to changing network conditions.</p> <p>During any network disruption, the system quickly provides information and direction to the motorist at critical locations in their journey to make their journey as safe and efficient as possible.</p>

Section 7

Summary – Performance requirements for Managed Motorways tools

This section provides an overview of the system architecture used for each of the three tool chains to manage traffic entering the freeway, on the freeway and exiting the freeway. These tool chains have been separated only for the purpose of this Framework to simplify the concept of the system for the reader, and in reality will all be combined within an integrated Managed Motorways system architecture.

System architectures are also provided for system-to-system interfaces between VicRoads and other road operators, which illustrate how certain tools such as coordinated ramp signals must be managed via the Traffic Software of the State (TOSS), which is under the operation of VicRoads, in order for route optimisation to take place. Other systems, such as vehicle detectors and CCTV can be operated and monitored by other road operators but must still interface with the TOSS in order to provide real-time data and visibility of the network to support algorithm operations and fine-tuning.

This section importantly contains a set of critical system component requirements for Managed Motorways operation and optimisation, based on the system performance criteria (qualities) outlined in Section 6.

These requirements should be directly inserted to contractual specifications for design, delivery, operation and maintenance of Managed Motorways systems. This includes performance requirements for system-to-system interfaces as well as availability and response time requirements for maintenance contracts.

The achievement of the performance requirements outlined in this section will help ensure that when operational the enabling technologies are able to create and sustain the benefits to road users, and should be used as a validation during the handover phase as per the best practice Systems Engineering process outlined in Section 1.2.



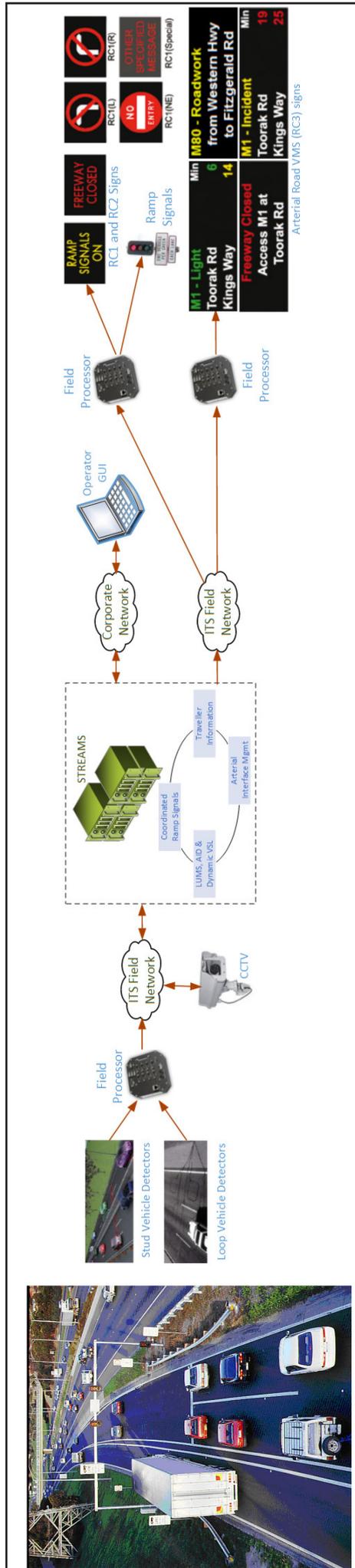


Figure 7.1 VicRoads tool chain for management of traffic entering the motorway

7. Performance requirements for Managed Motorways tools

This section of the Framework translates the content of the preceding chapters into specific performance requirements suitable for use in procurement contract specifications. It first introduces tool chain diagrams for managing traffic entering the motorway, traffic on the motorway and traffic exiting the motorway (Sections 7.1 to 7.3) and considering network wide management (Section 7.4). It then provides a table of performance requirements that combines these locations for managing traffic (Section 7.5), followed by specific system-to-system interface (Section 7.6) and maintenance requirements (Section 7.7).

7.1 Managing traffic entering the motorway

This section describes the architecture for the tool chain used to manage traffic entering the motorway, as illustrated in Figure 7.1. This includes the following tools:

- **Coordinated ramp signals (CRS):** This function manages the flow of traffic on entry ramps in order to prevent flow breakdown at motorway bottlenecks.
- **Entry ramp management system:** This function provides the ability to close a motorway entry ramp when required to manage an incident. Any entry ramp closure must also provide modified operation of the surrounding traffic signals to manage the additional traffic arising. The implementation of the "Freeway Closed" display is normally interlocked with the change of phasing at the on-ramp entry intersection controller.
- **Arterial road interface management system:** This function provides the ability to divert traffic away from the motorway when there is severe congestion or an incident, and even prevent traffic from entering the ramp when there is a motorway closure or emergency vehicle access is required.
- **Variable message signs (VMS):** This covers the roadside traveller information functions required to support the above tools
- **Vehicle detectors and CCTV:** To provide network intelligence functions.

The diagram only shows the components required for managing traffic entering the motorway. The full managed motorway toolkit is illustrated in Figure 7.8. The specific performance requirements arising for each component of the tool chain are listed in Section 7.5.

Figure 7.2 describes the timing constraints currently associated with the operation of CRS in STREAMS.

Where another road operator manages part of the road network, the interconnected systems must be capable of delivering all of the operational outcomes, even if some of the field equipment is connected to the road operator's system. For CRS, the architecture implemented is to connect the data collection equipment (vehicle detectors and CCTV) to the road operator's systems and the control equipment (ramp signals and associated signs) to VicRoads STREAMS system, with an interface between the systems to allow the real-time flow of detector data to the CRS algorithm on STREAMS (refer to Figure 7.3). The connection of all ramp signal control equipment to STREAMS ensures that the coordination of the ramp signals operation can seamlessly extend across road operations boundaries

Figure 7.3 only shows the components required for managing traffic entering the motorway. The full managed motorway toolkit for multiple road operators is illustrated in Figure 7.9.

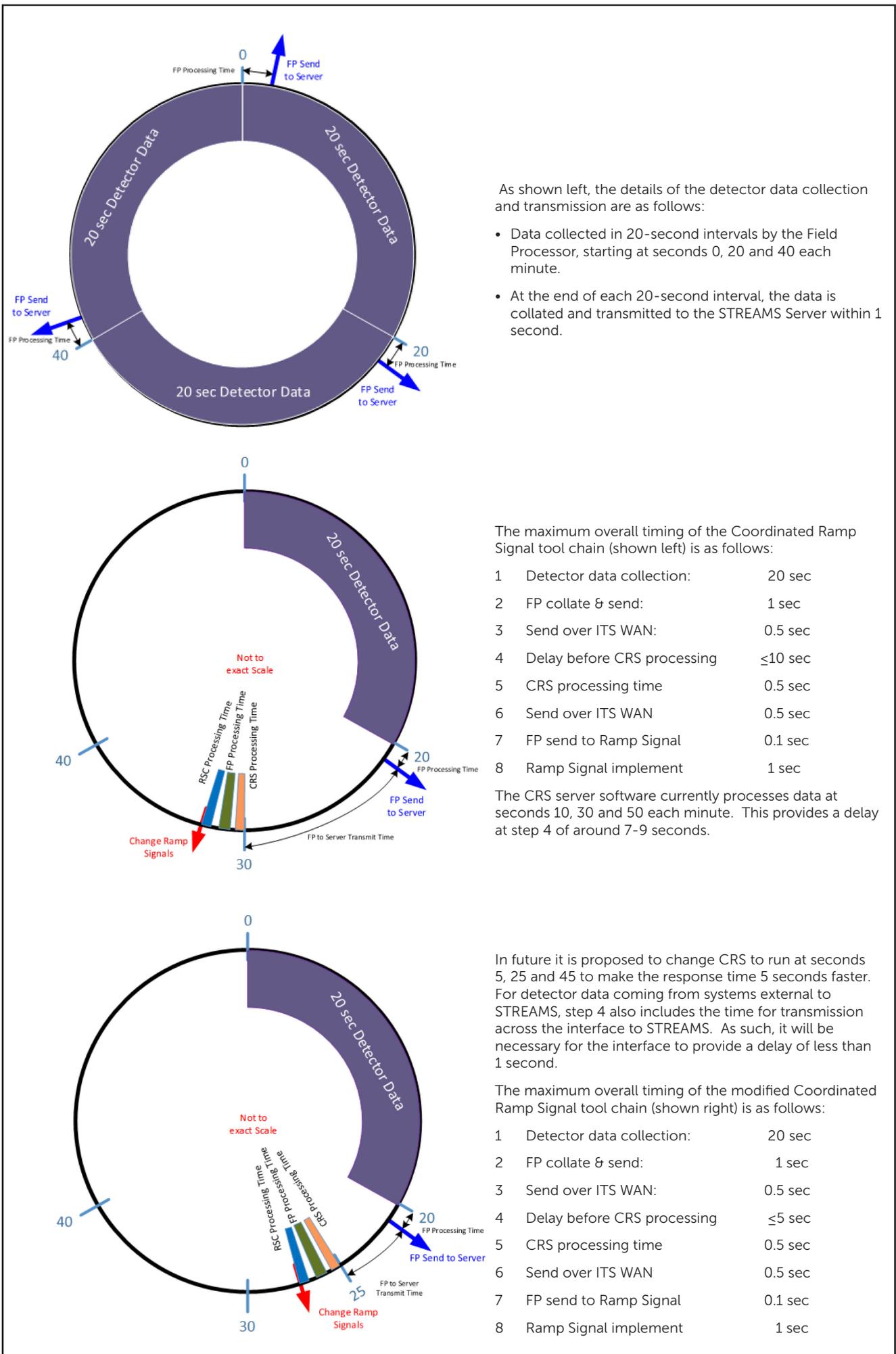


Figure 7.2 Timing constraints associated with operation of CRS in STREAMS

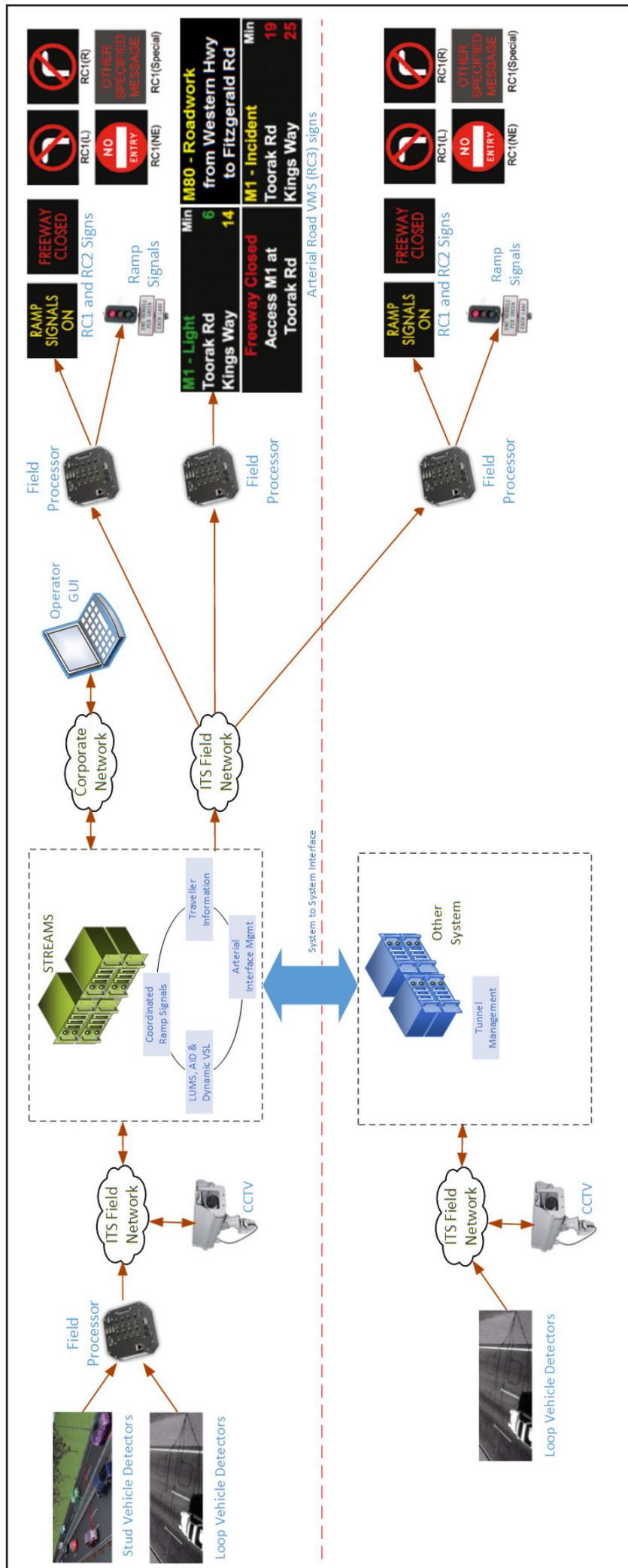


Figure 7.3 Multi-operator tool chain for management of traffic entering the motorway (VicRoads above, other road operator below)

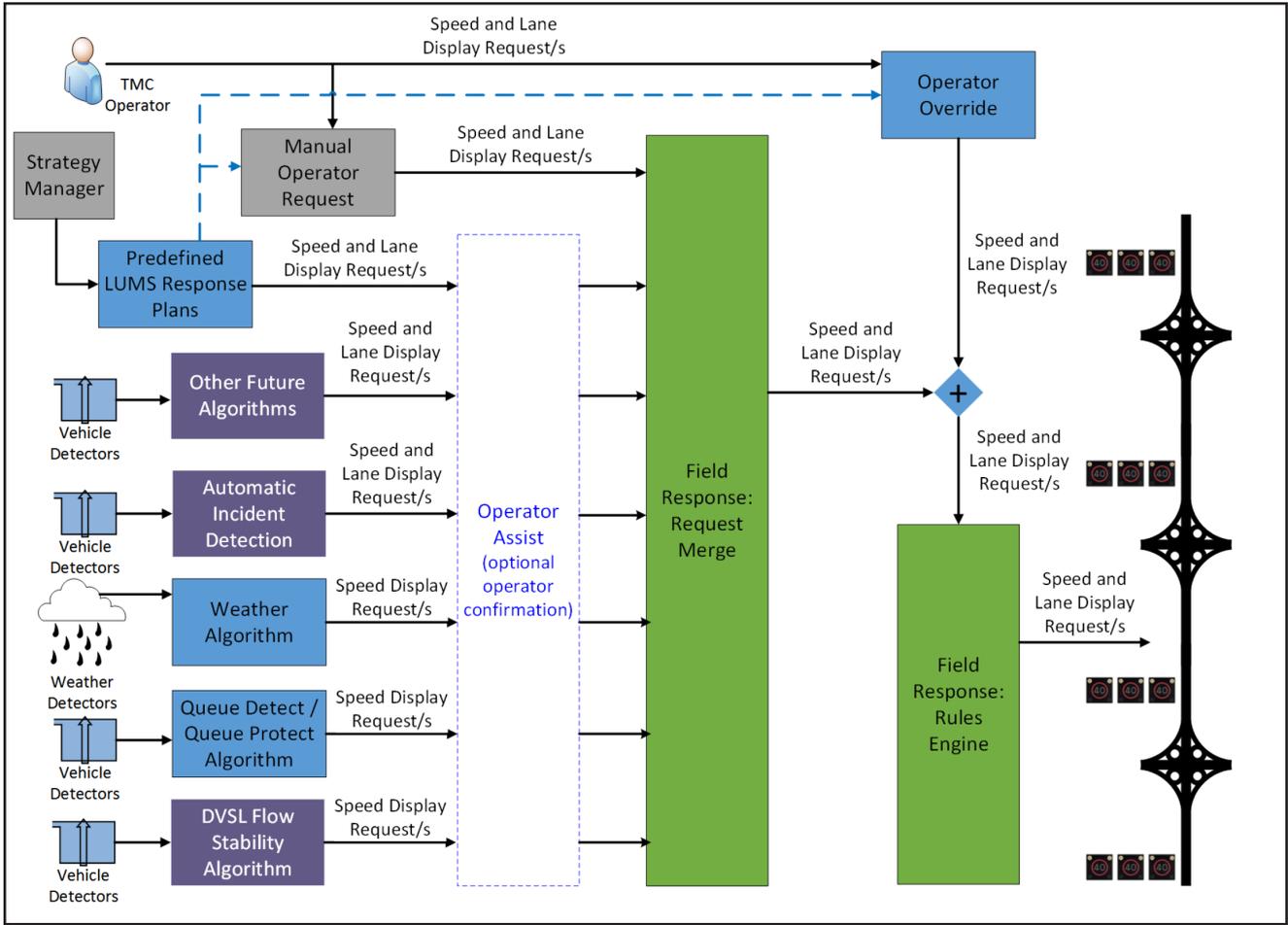


Figure 7.4 Proposed LUMS Operational Architecture

7.2 Managing traffic on the motorway

This section describes the architecture for the tool chain used for integrated speed and lane use management (LUMS) and associated technologies (refer to Figure 7.4). This includes the following tools:

- Lane Use Management System: This includes functionality for Lane Control and variable speed limits.
- Dynamic Variable Speed Limits: This is effectively a LUMS installation without Lane Control functionality.
- Traveller Information: This covers the traveller information functions required to support the above tools
- Vehicle detectors, CCTV, automatic incident detection systems and weather detectors: To provide network intelligence functions.

In future it is proposed that the complete LUMS operational architecture would look similar to that shown in the diagram at right, with the complete set of tools offering the following functions:

- Automatic Incident Detection (AID), which uses a variety of algorithms to detect incidents (including congestion) on motorways and instigate operator alerts and/or automatic speed reductions. This does not refer to the current STREAMS AID functionality, but proposed future functionality that will lead to an automated or semi-automated LUMS and/or CRS response
- Weather algorithm which uses weather detectors (or external weather data sources) to trigger speed reductions for affected areas. Typical uses would be for water in running lanes, slippery roads due to light rain and for poor visibility due to heavy rain/smoke/fog.
- Queue Detection/Queue Protection algorithm which detects the formation of a queue on the motorway and will implement speed buffers to protect the back of the queue. As a queue propagates on the motorway, the LUMS speed display propagates also to ensure that all approaching vehicles see the speed reductions before encountering the queue.
- The DVSL Flow Stability and Mainline Bottleneck Management algorithm shown in the diagram is a proposed future development.
- Operator Assist, which optionally allows the speed display requests made by the automatic responding algorithms (AID, Weather, QD/QP and DVSL) to be confirmed or modified by an operator before implementation.
- Field Response: Request Merge which creates a single merged request from the algorithms, strategy manager requests and manual operator requests. The merged response implements the lowest speed requested by any algorithm for each gantry. Lane control symbols take higher priority than speed displays.
- Manual Operator Request allows the operator to close lanes and reduce speeds as part of the merged response.
- Pre-defined Response Plans allows a set of pre-determined LUMS speed and/or lane closure displays to be added to the merged response plan. This may be initiated by an operator a Strategy Manager in response to the appropriate stimulus.
- Operator Override provides the ability for the operator to raise an automatically implemented speed limit or open a closed lane.
- Field Response: Rules Engine implements the policy rules associated with ensuring the appropriate speed buffers, lane tapers and other MUTCD requirements are implemented.

The current status of each of these is discussed in more detail in Appendix B.

The current motorway mainline equipment tool chain is as shown in Figure 7.5.

Figure 7.5 only shows the components required for managing traffic on the motorway. The full managed motorway toolkit is illustrated in Figure 7.8. The specific performance requirements arising for each component of the tool chain are listed in Section 7.5.

Figure 7.6 illustrates the current control of LUMS across the Melbourne freeway network. Of the private road operators in Melbourne, only CityLink and EastLink presently have a variable speed limit / lane control system capability. In both of these cases, the existing capability is associated with the management of safety for a tunnel. While the field equipment is similar, these systems are functionally different to the operation of LUMS as described in this document. Tunnel VSL/LC systems are primarily concerned with incident management in order to maintain tunnel safety - there is no specific capability to optimise the operation of the tunnel and manage it as part of an overall road network.

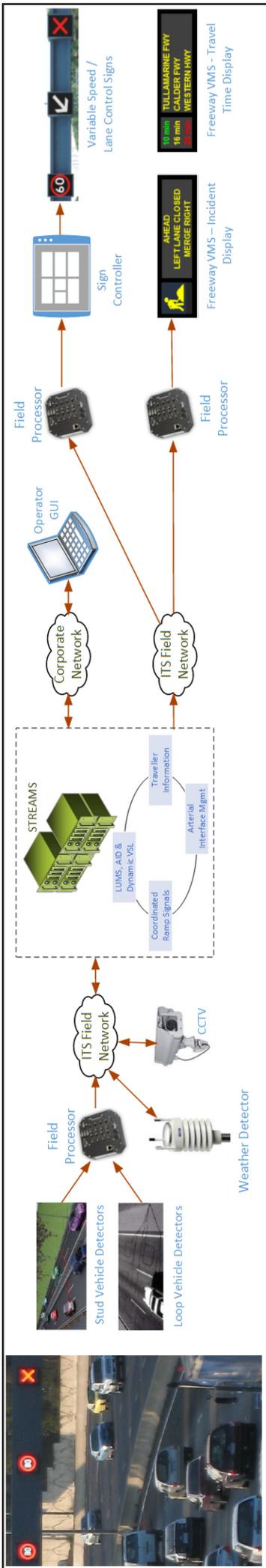


Figure 7.5 VicRoads tool chain for management of traffic on the motorway

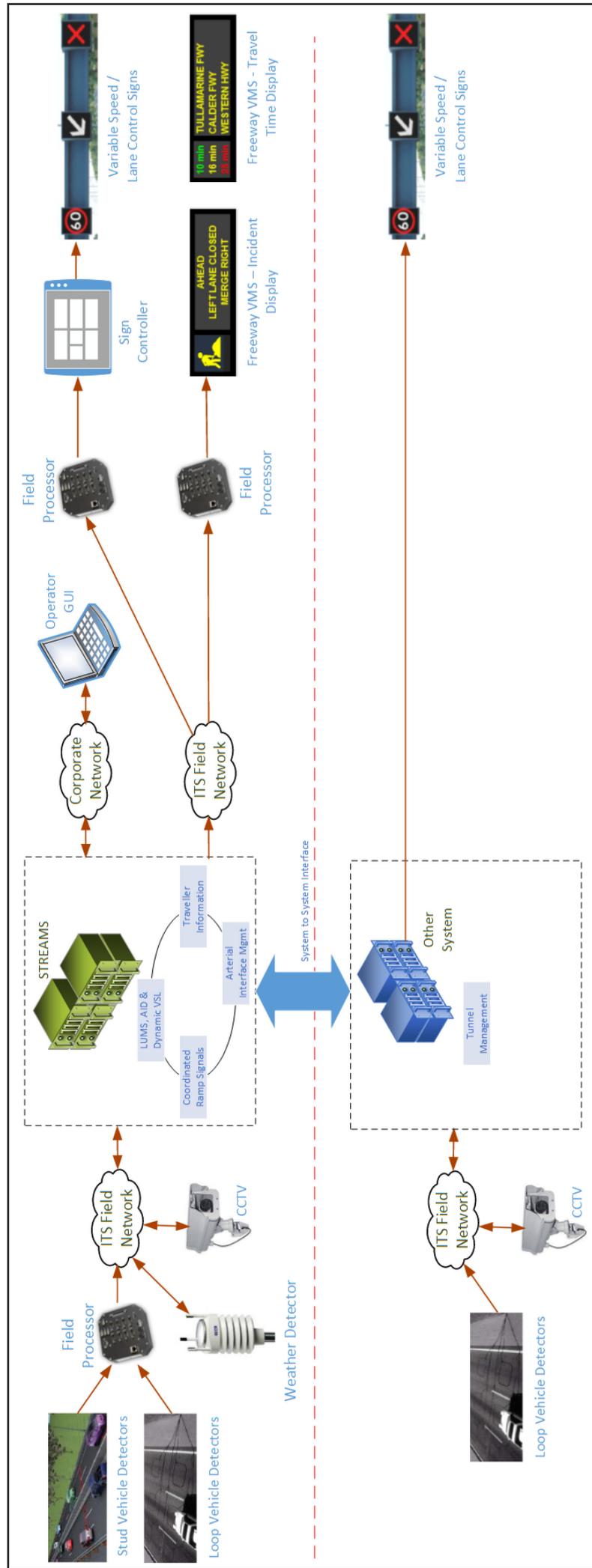


Figure 7.6 Multi-operator tool chain for management of traffic on the motorway (VicRoads above, other road operator below)

7.3 Managing traffic exiting the motorway

This section describes the specific requirements for the tool chain used to manage the exit from the motorway including the interfaces to the surface road network (refer to Figure 7.7). This includes the following tools:

- **Exit ramp management system and arterial interface management system:** These functions provide the ability to prevent (or minimise) queues forming on the exit ramp from extending onto the mainline freeway. Any reallocation of green time to favour the exit ramp movement at the surface road intersection must minimise adverse impacts on the coordination of the connecting surface road network.
- **Wide area network dispersion (WAND):** This function provides the ability to widely distribute the freeway traffic load into the surface road network in the event of a major freeway incident. This function also includes modified operation of the surrounding traffic signals to manage the additional traffic arising.
- **Variable message signs (VMS):** This covers the traveller information functions required to support the above tools
- **Vehicle detectors and CCTV:** To provide network intelligence functions.

End-of-motorway management systems (still in development) and WAND infrastructure have not been explicitly included in Figure 7.7, but are likely to use the same roadside infrastructure as well as additional tools on the mainline itself (refer to Section 7.2).

Figure 7.7 only shows the components required for managing traffic exiting the motorway. The full managed motorway toolkit is illustrated in Figure 7.8. The specific performance requirements arising for each component of the tool chain are listed in Section 7.5.

7.4 Network wide traffic management

The fifth and top layer of active management is multi-modal network optimisation with journey management. In this layer, the approach requires the simultaneous optimisation across network links and different user groups to achieve a 'one network' optimum that also optimises user journeys. It will also require enhancement of the Arterial Road Management System to support greater integration with the motorway management system.

This builds upon the route optimisation, traffic management and control interventions, traveller information and network intelligence in the other four layers of active management. The other four layers also manage the whole of the road network, but without that additional explicit simultaneous optimisation of that fifth layer. The requirements in Sections 8.1 to 8.3 cover both the motorway network and its interactions with surface roads but without the additional sophistication and complexity of the fifth layer. This fifth layer does not yet exist in operation, and this section of the report is reserved to provide for its future inclusion.

7.5 System component performance requirements

The overall system architecture required for VicRoads to deliver the current and future Managed Motorways capability is shown in Figure 7.8. This diagram is a merge of the individual tool chain diagrams from Sections 7.1 to 7.3, showing the complete equipment architecture.

As can be seen in Figure 7.8, the whole tool chain of service delivery for each Managed Motorways function requires components from different vendors in order to achieve the desired outcomes with the required performance. The range of vendors includes providers of roadside equipment, communications networks, computer hardware and software. In order to meet particular performance targets for the whole tool chain, it is necessary to assign performance targets to the individual components to guarantee that the overall target is met. Table 7.1 breaks down the overall system architecture into a set of discrete components and defines the component performance requirements to be included in the individual specifications and contracts used for procurement (based on the performance qualities outlined in Section 5).

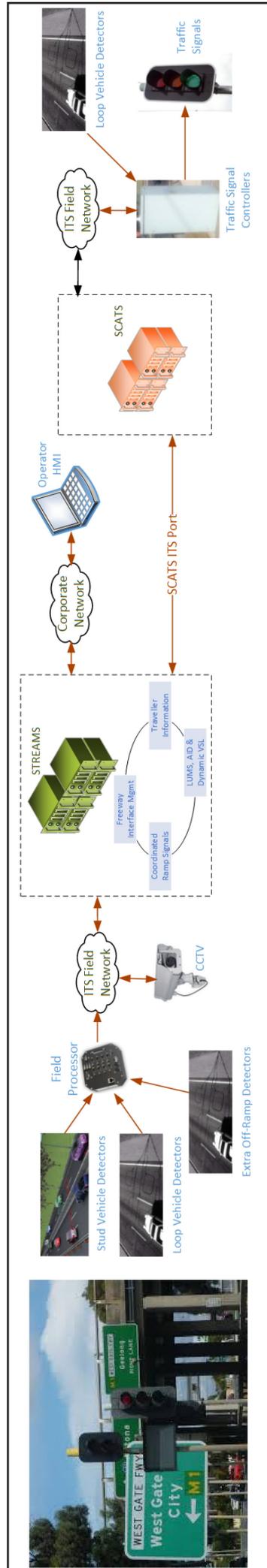


Figure 7.7 VicRoads tool chain for management of traffic exiting the motorway

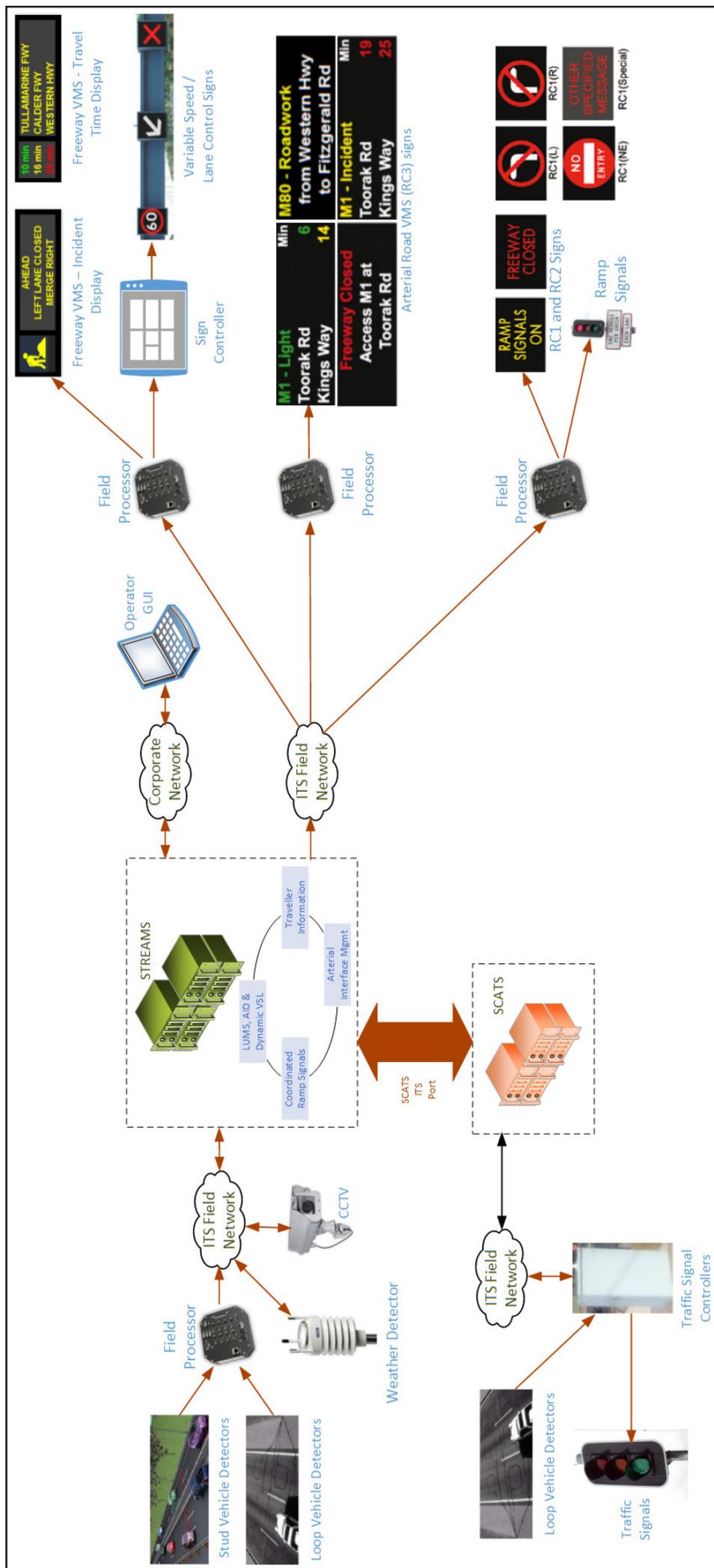


Figure 7.8 VicRoads overall system architecture for Managed Motorways

Table 7.1 System component requirements for Managed Motorways

Quality	Performance target	Vehicle detectors	Field processor (FP)	ITS field network	CCTV	ITS software	Corporate network	GUI	Ramp signals	Ramp signs (RC1 and RC2)	LUMS and VSL	VMS (RC3 and mainline)	SCATS Interface	SCATS and Traffic Signal Controllers
Accurate	The information collected and controls provided are representative of and appropriate for the current traffic conditions	Maximum occupancy error is 5% (eg. 19-21% reading range) and maximum speed error is 5%, both on a lane by lane basis at the 20 second interval*. Maximum volume error is 2%	FP time always synchronised to within 1 second of reference time	No requirements	CCTV responds accurately to control	All requested changes to ITS control devices are appropriate for current conditions on the motorway	No requirements	The HMI accurately represents the status of all field equipment & collected road condition data	Implementation of lantern display times are within 100msec of requested times	Ramp sign displays are appropriate for current motorway conditions	Changes to LUMS and VSL are appropriate for motorway conditions and controls	Messages on VMS are appropriate for motorway conditions and controls	Implementation of intersection lantern display times are within 100msec of requested times	Traffic signal controller lantern displays are appropriate for control strategies
Consistent	Data collection and controls are consistent across all motorways	Measurement of occupancy is consistent for same traffic density across all detectors	Response time of FP to implement control requests does not cause uncoordinated road network operations	Consistency to be met through meeting minimum performance requirements >99% of the time	All CCTV respond similarly to control requests	The operations of ITS control devices should be consistent across all motorways to provide a similar travelling experience	Consistency to be met through meeting minimum performance requirements >99% of the time	The HMI interface is consistent in menus and controls used for operations	The operation of ramp signals is consistent with current control strategies and consistent across all motorway segments	Implementation of ramp signs is consistent with current control strategies and consistent across all motorway segment	Implementation of LUMS & VSL displays are consistent with current control strategies and consistent across all motorway segments	VMS message displays are consistent with current control strategies and consistent across all motorway segments	Implementation of SCATS control changes are consistent with the objectives of the road network strategy being implemented	Implementation of SCATS control changes are consistent with the objectives of the road network strategy being implemented
Coordinated	Response strategies are implemented across all affected ITS devices within an appropriate time window	No requirements	Response time of FP to implement control requests does not cause uncoordinated operations of ITS control devices	No requirements	No requirements	The control software algorithms interact with all required ITS control devices and traveller information management software	No requirements	The HMI allows the operator to coordinate other ITS device responses with control responses	Operation of any ramp signal may be used to support a requested control strategy	Operation of any ramp sign may be used to support a requested control strategy	Operation of any LUMS or VSL may be used to support a requested control strategy	Operation of any VMS may be used to support a requested control strategy	SCATS interface provides functions to allow coordination of motorway and arterial operations	SCATS system and intersections provides functions to allow coordination of motorway and arterial operations
Coverage	Appropriate coverage of network, intelligence, information and control devices	Spacing and placement of vehicle detectors as per FRSH Chapter 5.2.1	No requirements	No requirements	Requirements in FRSH Section 6.4.15, MFH Section 2.9 and MFG Section 3.3	No requirements	No requirements	Full visibility of CRS software parameters, settings and live values is provided.	Requirements in FRSH Section 6.4, MFH Section 2.8 and MFG Section 3.7	Requirements in FRSH Section 6.4.12, MFH Section 2.8 and MFG Section 3.7	Requirements in MFH Section 2.5 and MFG Section 3.9	Requirements in MFH Section 4.5 and 4.6 and MFG Section 3.11 to 3.14	No requirements	No requirements

Quality	Performance target	Vehicle detectors	Field processor (FP)	ITS field network	CCTV	ITS software	Corporate network	GUI	Ramp signals	Ramp signs (RC1 and RC2)	LUMS and VSL	VMS (RC3 and mainline)	SCATS Interface	SCATS and Traffic Signal Controllers
Efficient	Efficient operation of the road enabled by minimum workload on operations staff	No requirements	No requirements	No requirements	CCTV allows use of programmable pre-sets	Changes made to motoway control require minimal (if any) operator input. LUMS operation is visualised and controlled by an operator using schematics	No requirements	The system requires minimal or no input from operators. Where operator input is required, the appropriate control can be requested with minimal operator input. GUI provides optional operator confirmation of automated speed limit changes	No requirements	No requirements	No requirements	No requirements	SCATS ITS Port support implementation of strategies to optimise performance of whole road network, not individual junctions or routes	Operation of SCATS optimises performance of whole road network, not individual junctions or routes
Fault tolerant	The system is designed to provide full functionality where a minor fault exists.	Number and location of detectors should ensure that control algorithms will not cease to operate due to a single detector fault	No requirements	The core of the ITS Field Network and network connection for critical devices has no single point of failure	Each section of motoway covered by more than one CCTV	The operation of the control software will not be compromised by a minor system fault	The core of the Corporate Network and TMC network has no single point of failure	No requirements	No requirements	No requirements	No requirements	No requirements	No requirements	No requirements
Integrated	Any ITS Device can be requested to operate as part of an integrated control response	Detector data is made available to the all control algorithm software and other processes as required	No requirements	No requirements	CCTV displays from one road operator is transparently distributed to other road operators	All system algorithms are able to operate with other ITS to request or provide operational functions	No requirements	As much as possible, status and operations functions will be integrated into a single GUI	No requirements	No requirements	No requirements	No requirements	SCATS interface supports requests and status updates that allow network-wide optimisation strategies to be implemented and monitored	Implementation of Traffic Signal control changes are able to be included in a response strategy
Real-time	The appropriate road network control calculation frequency and maximum implementation time is: CRS: 20, 1 sec LUMS: 2, 2 sec	Change in detector state caused by vehicle movement to be detected within 10 msec	Detector data must be collated and sent every 20 seconds Changes to Ramp Signal sent within 100msec Changes to LUMS & VMS made within 1 second	The ITS Field Network must be able to support the volume of real-time data transfer for all ITS equipment	The minimum CCTV picture refresh rate is 5 frames per second	The control software processes data at the required minimum data frequency: CRS: 20 sec LUMS: 2 sec	The Corporate /TMC Network must be able to support the desired refresh frequency of the HMI and CCTV displays	The GUI display is able to display updated status data for all ITS devices and road networks from the STREAMS Server	Ramp signal control changes within 1 second of a change being requested	Ramp sign display changes within 1 second of a change being requested	LUMS control changes within 2 seconds of a change being requested	VMS display changes within 15 seconds of a change being requested	SCATS interface sends data updates within 1 second of a change. SCATS Interface control requests changes within 100 msec of a change being requested	SCATS requests control changes within 2 seconds of a change being requested

Quality	Performance target	Vehicle detectors	Field processor (FP)	ITS field network	CCTV	ITS software	Corporate network	GUI	Ramp signals	Ramp signs (RC1 and RC2)	LUMS and VSL	VMS (RC3 and mainline)	SCATS Interface	SCATS and Traffic Signal Controllers
Regulatory and enforceability	All regulatory controls support enforcement where required	No requirements	No requirements	No requirements	No requirements	No requirements	No requirements	No requirements	Displays must meet requirements of Road Rules	Displays must meet requirements of Road Rules	Displays must meet requirements of Road Rules Displayed speed values must be output to enforcement systems upon request	No requirements	No requirements	Displays must meet requirements of Road Rules
Reliability and maintenance	All tool chains used for road network control must be fully operable 99.5% of the time	Priority vehicle detector availability 99%, normal 97% Section 7.7 covers maintenance requirements	FP availability 99.5% Section 7.7 covers maintenance requirements	ITS Network availability 99.9% Section 7.7 covers maintenance requirements	CCTV availability 97% Section 7.7 covers maintenance requirements	ITS algorithms and software (incl hardware, etc.) availability 99.9% Section 7.7 covers maintenance requirements	Corporate Network availability 99.9% Section 7.7 covers maintenance requirements	GUI service availability 99.9% Section 7.7 covers maintenance requirements	Ramp Signals availability 99.5% Section 7.7 covers maintenance requirements	Ramp Signs availability 97% Section 7.7 covers maintenance requirements	Priority LUMS availability 99%, normal 97% Section 7.7 covers maintenance requirements	VMS availability 97% Section 7.7 covers maintenance requirements	Average SCATS Interface availability 99.9% Section 7.7 covers maintenance requirements	Average Traffic Signals availability 99.9% Section 7.7 covers maintenance requirements
Robust	The system is designed have minimum risk of fault	Only proven vehicle detectors should be used	Only proven field computers should be used	The core of the ITS Field Network should provide redundant communication paths Critical ITS Devices should be connected to the core network	Only proven CCTV should be used	CRS software should be designed to detect non-operation & automatically restart	The core of the Corporate Network should provide redundant communication paths	GUI should be designed to be stable and support 24x7 operation	Only proven ramp signal controllers and lanterns should be used	Only proven ramp signs should be used	Only proven LUMS equipment should be used	Only proven VMS should be used	No single point of failure on the STREAMS – SCATS interface	Only type approved traffic signal controllers are used
Safe	The implemented ITS improves the safety of the road.	No requirements	No requirements	No requirements	No requirements	No requirements	No requirements	No requirements	No requirements	No requirements	The LUMS site controllers ensures that the VSL/LC display for each lane at the site will be safe	No requirements	No requirements	No requirements
Seamless	Data collection & distribution and control strategies operate across system-to-system boundaries transparently to road operators and clients	Detector data from systems other than STREAMS can be used by any control algorithm	No requirements	The ITS Field Network can use a wide variety of different technologies seamlessly	CCTV displays from one road operator is transparently distributed to other road operators	The control software can use appropriate real-time detector data from STREAMS or other interfaced systems	The Corporate Network can use a wide variety of different technologies seamlessly	If multiple systems exist, the GUI shall provide integrated display and control	Ramp signals for other road operators can be run on the VicRoads STREAMS system	Ramp signs for other road operators can be run on the VicRoads STREAMS system	Implementation of LUMS strategies shall always provide smooth transitions between road segments with different speed or lane controls	Implementation of VMS messages supporting motorway operation shall be integral to dynamic control algorithms in the system	All capabilities offered by the interface shall be supported seamlessly in STREAMS	Intersection controllers for other road operators can be run on the VicRoads SCATS system

Quality	Performance target	Vehicle detectors	Field processor (FP)	ITS field network	CCTV	ITS software	Corporate network	GUI	Ramp signals	Ramp signs (RC1 and RC2)	LUMS and VSL	VMS (RC3 and mainline)	SCATS Interface	SCATS and Traffic Signal Controllers
Secure	No unauthorised access to any part of the tool chain	Detector operation shall have minimal risk of external interference	Access to the FP and delivery of updated data to and control from the server shall be via secure connection	The ITS Field Network shall provide appropriate security to prevent unauthorised access	Only authorised users shall have view or control access to CCTV	The ITS Software prevents any unauthorised access to information or control of equipment. The ITS Software logs and reports all detected security events, including failed access attempts.	The Corporate Network shall provide appropriate security to prevent unauthorised access	The GUI shall provide appropriate security for access & user control	Ramp Signals only respond to authorised control requests from an FP	Ramp Signs only respond to authorised control requests from an FP	LUMS and VSL only respond to authorised control requests	VMS only respond to authorised control requests	The interface shall not provide opportunity to compromise the security of either STREAMS or SCATS	Traffic Signals only respond to authorised control requests from SCATS and hard-wired controller inputs
Timely	Changes to road traffic conditions will cause appropriate control changes within the times specified: CRS: 30 (soon 25) sec LUMS: 25 sec	Change in detector state caused by vehicle movement to be advised within 50 msec	Detector data must be collected at least every 2 seconds and sent within 1 second of the end of each data collection period Control device change must be implemented immediately	Maximum network delay of 500msec for transfer of detector data & control commands – even under full CCTV load	Maximum delay between control request and CCTV movement is 100 msec to avoid CCTV control overshoot	The maximum age of data to be processed by the control system software is: CRS: 10 (soon 5) sec LUMS: 10 sec	Maximum network delay of 500msec for transfer of GUI status and control commands – even under full CCTV load	The GUI display must show the updated status within 5 seconds of the STREAMS Server	Ramp signal control changes within 1 second of a change being requested	Ramp sign display changes within 1 second of a change being requested	Changes to LUMS controls occur within 5 seconds of a change being requested	Changes to VMS displays occur within 5 seconds of a change being requested	SCATS interface control changes within 1 second of a change being requested	Traffic signal controls change within 1 second of a change being requested

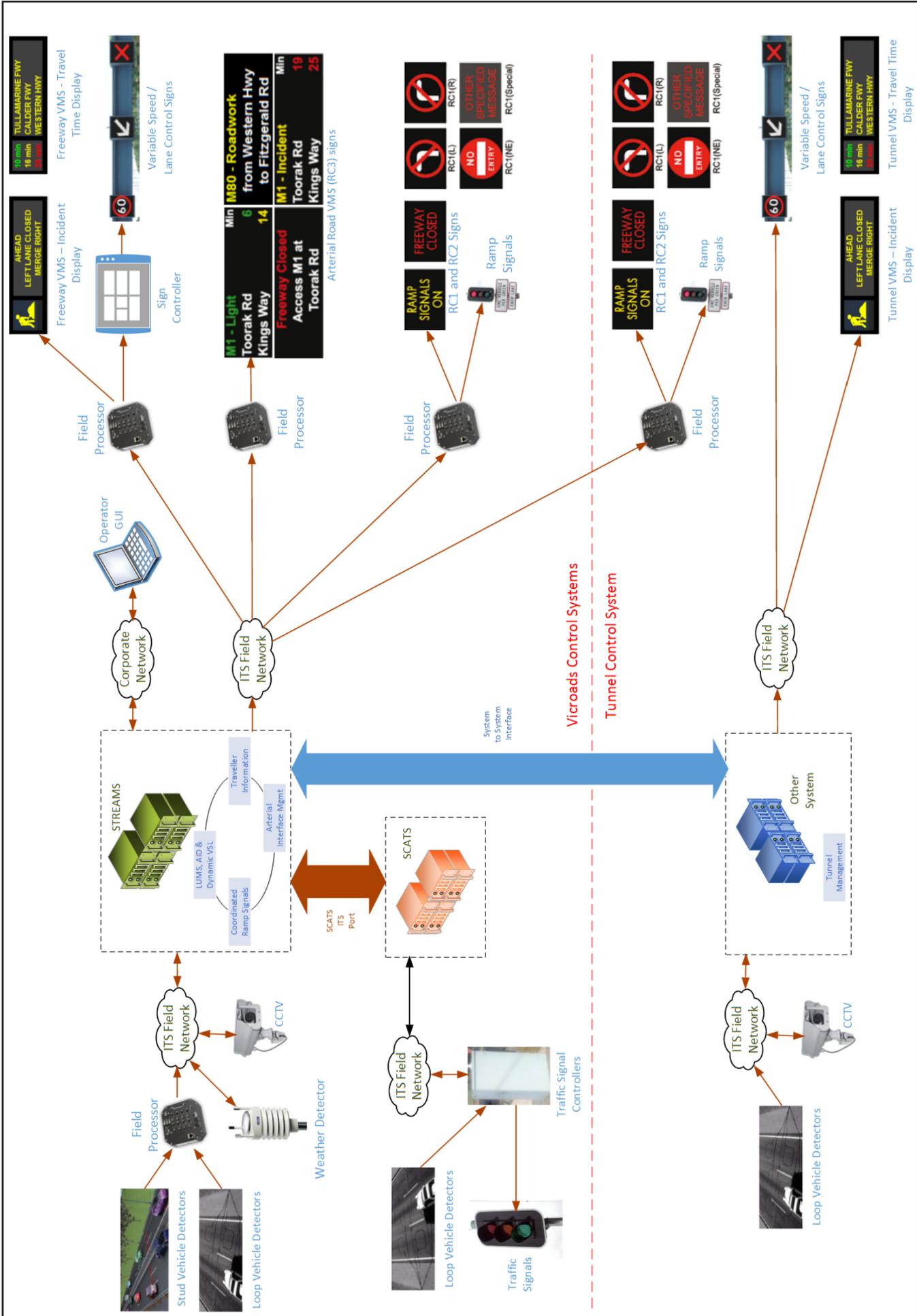


Figure 7.9 VicRoads system-to-system architecture for Managed Motorways including tunnel environments (VicRoads above, other road operator below)

7.6 System-to-system interface performance requirements

Where another road operator manages part of the road network, the interconnected systems must be capable of delivering all of the operational outcomes, even if some of the field equipment is connected to the road operator's system. As a part of preparing this report, a separate discussion paper (Johnston, 2014) was prepared to examine the architectural options for the implementation of the desired managed motorways capability in a multiple road operator environment. In accordance with the conclusions of the Managed Motorways Architecture Options paper, a separate control system is only recommended where the safety requirements of a tunnel required a separate safety-critical system to be used. In all other cases, the additional complexity introduced would either compromise the performance of the road network or add significant additional costs without any operational benefit. The following diagram shows the recommended architecture to be used to provide the full suite of Managed Motorways to a tunnel environment.

Where a separate system is used by an alternate road operator to manage a section of motorway, the additional requirements listed in Table 7.2 arise. These are the requirements that arise in addition to those listed in Table 7.1. Note that while further work needs to be done on the Managed Motorways Architecture Options paper (Johnston, 2014) which may impact on the diagram above, the requirements listed below should remain unchanged.

Table 7.2 Additional requirements to manage a motorway if a System-to-System interface is used

Attribute	Extended tool chain target	Additional partner system and interface requirements arising
Accurate	The information collected and controls provided are representative of and appropriate for the current traffic conditions.	Detector data collected must have the same accuracy requirements as VicRoads system. System time synchronised within 1 second of reference time.
Consistent	Data collection and controls are consistent across all motorways. For example, occupancy data collected across all motorway systems is based on same effective detection zone size	Spacing and specifications for intelligence equipment (e.g. vehicle detectors and CCTV) as per VicRoads system. Detector data collected is similar to VicRoads data for same traffic conditions. For example, occupancy data collected across all systems is based on same effective detection zone size. Operation of VSL/LC signs is consistent across all road segments.
Coordinated	Response strategies are implemented across all affected ITS devices within an appropriate time window.	All Ramp Signals being controlled by STREAMS provides a coordinated response. All equipment being directly or indirectly controlled by STREAMS provides a coordinated response within 5 seconds of a control request. For example, when a response plan is being implemented, all changes to VSL/LC signs must begin within 5 seconds of the request to change. All VSL/LC sign display changes must complete within a 2 second window.
Coverage	Appropriate coverage of intelligence, information and control devices.	Spacing and specifications for intelligence, information and control devices as per VicRoads system.
Efficient	Efficient operation of the road enabled by minimum workload on operations staff.	As per VicRoads system.
Fault tolerant	The system is designed to provide full functionality where a minor fault exists.	An active LUMS control strategy that extends across a system-to-system interface shall not be affected by a fault on the interface. The current control shall be maintained during any outage and the operators notified so that manual synchronisation of control can be implemented for the remainder of the outage.
Integrated	Any ITS Device can be requested to operate as part of an integrated control response.	The STREAMS – SCATS interface provides functions to allow control requests to be easily made and current status to be monitored.
Real-time	The appropriate ramp signal control is calculated and implemented every 20 seconds.	Detector data delivered across interface to STREAMS every 20 seconds.
Regulatory and enforceability	No additional requirements to those listed in Table 7.1.	As per VicRoads system.
Reliability and maintenance	The CRS tool chain must be fully operable 99.5% of the time.	As per VicRoads system. Applies to system-to-system interface design also.

Attribute	Extended tool chain target	Additional partner system and interface requirements arising
Robust	The system is designed have minimum risk of fault.	As per VicRoads system. Applies to system-to-system interface design also. No single component failure shall cause the interface to fail.
Safe	No additional requirements to those listed in Table 7.1	As per VicRoads system.
Seamless	Data collection & distribution and control strategies operate across system-system boundaries transparently to road operators and clients.	Detector data from other road operator appears in STREAMS transparently to operation of control software.
Secure	No unauthorised access to any part of the tool chain.	As per VicRoads system.
Timely	Changes to road traffic conditions will cause appropriate ramp signal control changes within 10 seconds of data collection. This timing should be reduced to 5 seconds.	Detector data delivered across interface to ITS software on STREAMS less than 2 seconds after each 20 second interval. Control requests delivered across interface & implemented within 5 seconds. In both of these cases, only 1 second of extra time is allowed for interface delay.

7.7 Availability and response time requirements

ITS service delivery is dependent on a chain of assets and processes working together to produce the final result, with any weakness in this chain leading to either loss or degradation of service regardless of the status of all other elements in the chain. The maintenance requirements for ITS assets and systems must be considered within the context of these value-creating chains of assets and processes working together. Understanding how ITS assets and systems interact to create value is a necessary part of setting practical and appropriately prioritised asset performance requirements. Some assets and systems will have higher requirements than others because of the extent of dependence on them by other parts of the value chains: this is particularly true of the central software that almost all value chains rely upon and is a reason why there are often several layers of resilience and redundancy provided for these central systems and networks.

The reliance of ITS-enabled services on ITS assets and systems means that availability becomes a key measure of asset and system performance. Availability is the relationship between the Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR): $A = \frac{MTBF}{MTBF + MTTR}$. Availability can be increased by increasing the MTBF of individual system components, reducing the MTTR or by introducing redundancy into the system to increase the MTBF of the overall system.

The relationship between availability, MTBF and MTTR means that by specifying two of these three, the third is implied. VicRoads' approach is to specify availability as the measure most closely linked to value creation by the asset/system and response time and rectification time as a contractual measure in lieu of MTTR.

In setting response and rectification times, prioritising maintenance works is a balance of partially competing needs:

- The need to protect public safety by addressing any hazards that may arise;
- The need to maximise value provided to the community by the ITS-enabled services;
- The need to contain or minimise the total costs of service delivery; and
- The need to minimise the traffic and other community impacts of carrying out maintenance work.

Providing a suitable balance in setting response and rectification times involves:

- Using specifications and incentivised procurement methods to increase MTBF to reduce the frequency of responses and the impact of rectification times on availability;
- Providing resilience and redundancy where appropriate (particularly in central systems and networks) so that individual failures have limited impact;
- Ensuring any safety hazards are addressed through prioritising faults of this class as critical faults that require shorter response and rectification times;
- Designing field installations so that traffic impacts of undertaking fault rectification works (and traffic management costs to do so) are reduced; and
- Allowing for contractors to address non-critical faults in a way that minimises traffic management costs and impacts.

There is little value in VicRoads setting response and rectification times for general faults that are unaffordable or impractical, as in all likelihood they will fall rapidly into effective disuse. Finally, in setting contractual availability requirements, it is important to note that these often differ from real availability performance due to the exemptions that often exist in contracts for disruptions outside the control of the contractor. An example is provided below in Table 7.3 for central systems and networks. This example is provided for discussion purposes and as such its inclusion in this Framework does not create a basis for contractors to rely upon.

Table 7.3 Summarised example requirements for availability and rectification

ITS Asset/System	Specific example	Required Real Availability	Required Contractual Availability	Required Initial Response	Required Rectification Time	Comment
Central control systems	STREAMS Application Server	99.9% (8.8 hours per year outage)	99.95% (4.4 hours per year outage)	1 hour (classed as critical)	2 hours (classed as critical)	Achieving availability performance is likely to require a resilient architecture so that individual failures do not cause the total system/network failure covered here.
Central communications networks	Core and distribution layers of communications system					
Field control system	Individual STREAMS Field Processor with several connected devices	99.5% (44 hours per year outage)	99.7% (26 hours per year outage)	2 hours (diagnosis and remote reset)	24 hours	Several assets are impacted by outages in these individual devices.
Communications system access	Communications to an individual Access Switch with several connected devices					
Vehicle detector – priority site	Individual vehicle detector at a site which is essential for route optimisation	99% (88 hours per year outage)	99.5% (44 hours per year outage)	4 hours (diagnosis and remote reset)	48 hours	Detector sites would be designed as priority sites based on their importance to achieving route optimisation.
Vehicle detector – normal site	Individual vehicle detector at other sites	97% (11 days per year outage)	98% (7 days per year outage)		7 days	
						Allowing 7 days for non-priority sites assist lowering traffic impacts and maintenance costs.

Section 8 Summary – Next steps

There are a number of important next steps in implementation of the VicRoads active management approach.

For those responsible for delivering and operating Managed Motorways projects and enabling technologies, the critical follow-on actions are to:

- Ensure that that Managed Motorways systems when built and ready for handover to operations are comprehensively validated against the high priority performance and technical requirements set out in this Framework, which will ensure that the technology can be operated and optimised as required (as per the System Engineering process in Section 1.2); and
- Plan for ongoing funding and resourcing for operation and optimisation activities that enable the technology to create and sustain the benefits for users.

For those responsible for applying and evolving the principles of active management described in this Framework across VicRoads and other road operator business areas, the focus is on:

- Further development of other motorway planning, design and operations guidelines to ensure alignment with the active management approach and to continuously develop and enhance the Managed Motorways toolkit;
- Further investigation of the future known and unknown impacts of smarter (automated and connected) vehicles that are starting to use our public road networks and which may change requirements for design and operation of Managed Motorways requirements going forward.

Appendix C should also be referred to for a complete list of proposed system developments and enhancements for the Managed Motorways toolkit (as identified earlier throughout Sections 4.3 to 4.5).



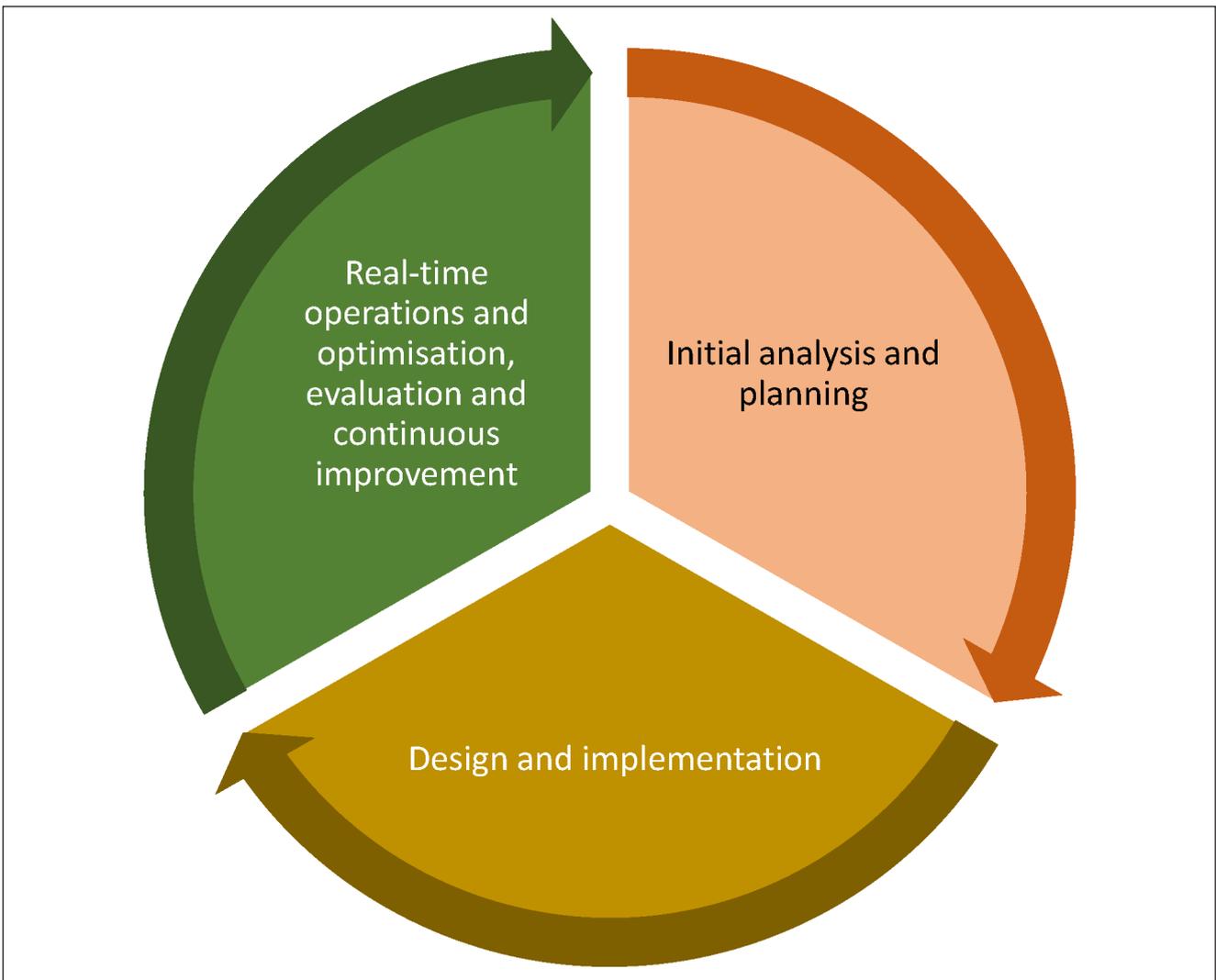


Figure 8.1 Lifecycle of active management

8. Next steps

There are a number of next steps that can be considered depending on the intended use of this document, which are summarised as follows and detailed in the sub-sections below. Sections 8.1 and 8.2 focus on actions for those responsible for delivering and operating the Managed Motorways system and enabling technologies, and Sections 8.3 and 8.4 provide guidance on those who wish to apply and continue to develop the active management approach set out in this Framework.

8.1 System validation against requirements

This Framework sets out a clear business rationale and performance requirements for Network Optimisation and Operations. These requirements become a critical subset of the performance technical requirements for each enabling technology element, complemented by other requirements that cover other dimensions. These requirements that are driven by network optimisation and operations are those that identify how the technology will be used to create value and for that reason they must be seen as the highest priority technical requirements. Any technology elements that do not fulfil the technology requirements set out in this Framework are not providing their intended value, regardless of how reliably, securely or economically that technology functions. As the requirements in this Framework are those that represent how business value is created, the validation step outlined in the Systems Engineering process (Section 1.2) should be performed against the requirements in this Framework.

8.2 Sustaining and improving operations

It is a truism that all of the benefits of active management are delivered through the operational stage - the initial analysis and planning and design and implementation are critical to getting the tools right, but it is the use of these tools that creates benefits for individual road users and the broader community (see Figure 8.1). This statement is useful for highlighting the need to actively manage the Managed Motorway. Indeed, not only must the Managed Motorway be actively managed, the extent to benefits realised for the money already invested are directly linked to how effectively the active management is undertaken.

The need for ongoing active management also highlights one of the inevitable characteristics of active management, which is a very different expenditure profile to traditional road assets. Active management solutions generally have low implementation costs relative to their benefits, but incur a higher proportion of those lower initial costs in then undertaking the active management. In a situation where government recurrent expenditure is under pressure, this profile can create some challenges. In other situations, such as toll roads, this characteristic is useful in better matching the expenditure profile to the revenue received over time from tolls.

The active management lifecycle diagram in Figure 8.1 also illustrates a further important opportunity of active management - the opportunity to continually get even greater performance from the road asset through incremental investments without significant changes to the underlying road asset. As road space continues to grow at a lower rate than road demand, this opportunity to continue to improve upon performance will become increasingly useful.

The opportunity for further improvement is firmly embedded in the approach taken to this Framework. Most notably there is opportunity to step up to higher levels of active management using the infrastructure already largely in place, for example using existing LUMS infrastructure for dynamic variable speed limits that can extend the effectiveness of the coordinated ramp signals already in operation.

8.3 Recommended guideline and system developments

Following the completion of this Framework, there would be value in VicRoads updating its Capability Maturity Models for active management, Managed Motorways and also arterial road network management. The layers of active management covered in Section 3 of this Framework were inspired by the Capability Maturity Model approach, which was substantially adapted to fit this particular situation. Now that adaptation has been used to assist the completion of the rationale and technical requirements for Network Optimisation and Operations, it would be possible to return to the more traditional Capability Maturity Model and clearly mark the current and target future states and as well as any notable interim states. This Framework has also highlighted that the future of active management of Melbourne's motorway network will involve an increasing number of road operators. The layers of active management approach assists in identifying some of the different functions that these different road operators may perform, and these differences make it relevant that Capability Maturity Models be completed for each road operator in addition to VicRoads.

The broad coverage of this Framework, including its discussion of new functionalities, means that there is value in updating VicRoads' current Concept of Operations documents for Managed Motorways to remain in step with these current and future approaches. Such ongoing updates are to be expected in an area of ongoing development such as this, and the updates are needed to avoid documents quickly becoming superseded.

VicRoads' operational manuals for Managed Motorways are a key part of VicRoads' capability in Managed Motorways. These manuals will require updating, to cover gaps highlighted by the additional guidance available through this Framework and to cover the continued development of Managed Motorways tools. Even when the development of Managed Motorways tools may slow or pause, continued development in operational methods means that the operational manuals should be subject to ongoing update as part of continual improvement.

The SmartRoads Guidelines (VicRoads 2013b) in particular could be further developed to provide an overall network objective target for MM optimisation, as discussed in Section 3.1.5.2.

A detailed list of all the potential future system developments listed in Section 4 is provided in Appendix C.

8.4 Impacts of smarter vehicles

The increasing intelligence of vehicles will have an increasing impact on road network operations over the next decade. A number of recent actions all point to the speed at which the trend towards smarter vehicles is moving:

- The Victorian Transport Accident Commission is advocating Auto Emergency Braking (AEB) as a follow-on from Electronic Stability Control and Anti-Lock Braking Systems, all of which take partial control from a driver at times the vehicle determines this to be necessary;
- Google has entered the automotive systems space and taken a strong position in automated vehicle technologies and a number of other companies are very active in this area;
- Trials of truck platooning on public roads and in mixed traffic are becoming more common; and
- The US National Highway Traffic Safety Administration has issued an advanced notice of proposed rule-making to mandate Cooperative ITS for light vehicles.

A number of barriers to widespread adoption of some technologies remain and the slow turnover of the vehicle fleet will keep on-road penetration rates low for several years, however the impacts of smarter vehicles will be far reaching and warrant discussion here.

There is a wide range of impacts of smarter vehicles, however some of the impacts most relevant to Managed Motorways include:

- The reduced risk of crashes may assist in improving safety and reliability and allow increasing focus on managing for efficiency with safer vehicles assisting to maintain and improve safety;
- Increased display capabilities in vehicles and increasing communication to those vehicles may reduce reliance on roadside traffic control and advisory infrastructure, although the lowest common denominator (least equipped vehicles) will still need to be catered for by road agencies;
- (Semi-)automated driving in congested conditions will change how vehicles proceed along the motorway;
- Vehicles may be able to communicate information to the road authority operational systems, to further improve the ability of the systems to detect and respond to changing traffic conditions;
- Any allowance for drivers to undertake other activities while driving will change the opportunity costs of congestion; and
- Any allowance for automated vehicles to operate without drivers may have substantial impacts on demand patterns.

One of these points warranting a particular focus is the increased use of automated or semi-automated driving in congested conditions, such as Adaptive Cruise Control and vehicle platooning. Although it has been demonstrated that it is theoretically possible for autonomous vehicles (without vehicle-to-vehicle or V2V communications) to operate in a way that increases road capacity, such as through reduced headways, research with a broader focus highlights that this is unlikely and that cooperative V2V communications between vehicles are likely to be required to achieve capacity increases.

The reasons for this discrepancy between theoretical possibility and likely reality are clear once the benefits, risks and costs to the individual vehicle purchasers and automotive manufacturers are considered. The community as a whole benefits from the increased capacity, however the individual vehicle purchaser is asked to bear this cost and the vehicle manufacturer the risk. The vehicle purchaser is likely to value Adaptive Cruise Control that operates safely and smoothly and perhaps that mimics their driving style rather one that compromises in those areas to provide a community benefit. The automotive manufacturer gains nothing from the exposure to any additional risk associated with Adaptive Cruise Control that works to maximise capacity and will understandably seek to minimise risk through a more conservative approach. This conservative approach may assist reliability of road performance through avoiding crashes, but will possibly reduce rather than increase capacity. Adding V2V communications allows for cars to be advised of the changes in speed occurring several vehicles ahead, allowing for significant risk mitigation in the automated operations and in this way assisting the focus to be on increasing throughput.

With regards to automated and connected vehicles, there are numerous 'known unknowns' as well as 'unknown unknowns' in terms of the impacts on transport planning and design and the level of benefits that can be achieved for motorway operations. While the timeframes for penetration and adoption scenarios are not certain, it is clear that more and more smarter vehicles will be using public roads in the future and there will be impacts on how existing systems operate.

As more research is undertaken and understanding of those impacts are improved, VicRoads will be in a better position to review this Framework and other Managed Motorways guidelines and update as required to ensure that the planning, design and operation of traffic on the road network considers management of smarter vehicles.

Acronyms

AID	Automatic incident detection
ALR	All lane running
ARMS	Arterial road management system
CCTV	Closed circuit television
bn	Billion
CBD	Central business district
CMM	Capability maturity model
CMS	Changeable message sign
ConOps	Concept of operations
CRS	Coordinated ramp signalling
DVSL	Dynamic variable speed limits
ELR	Emergency lane running
FP	Field processor
FRSH	Managed Freeway: Freeway Ramp Signals Handbook
FHWA	Federal Highways Association
GUI	Graphical user interface
HERO	Heuristic Ramp-metering cOordination
HMI	Human machine interface
ICT	Information Communication Technology
ILM	Investment logic map
ITS	Intelligent transport system
LH	Left hand
km	Kilometre
KPI	Key performance indicator
LUMS	Lane use management system
MFG	Managed Freeway Guidelines (VicRoads 2014)
MFH	Managed Freeway Handbook for Lane Use Management Systems, Variable Speed Limits and Traveller Information
MTBF	Mean time before failure
Mgt	Management
MTTR	Mean time to repair
Mwy	Motorway
RC1, 2 and 3	Ramp control (signs) 1, 2 and 3
RH	Right hand
SCATS	Sydney Coordinated Adaptive Traffic System
SVO	Speed, volume, occupancy
TOSS	Traffic Operating Software of the State
US	United States of America
V2V	Vehicle-to-vehicle
Veh	Vehicles
VKT	Vehicle kilometres travelled
VMS	Variable message signs
VSL	Variable speed limits
WAND	Wide area network dispersion

References

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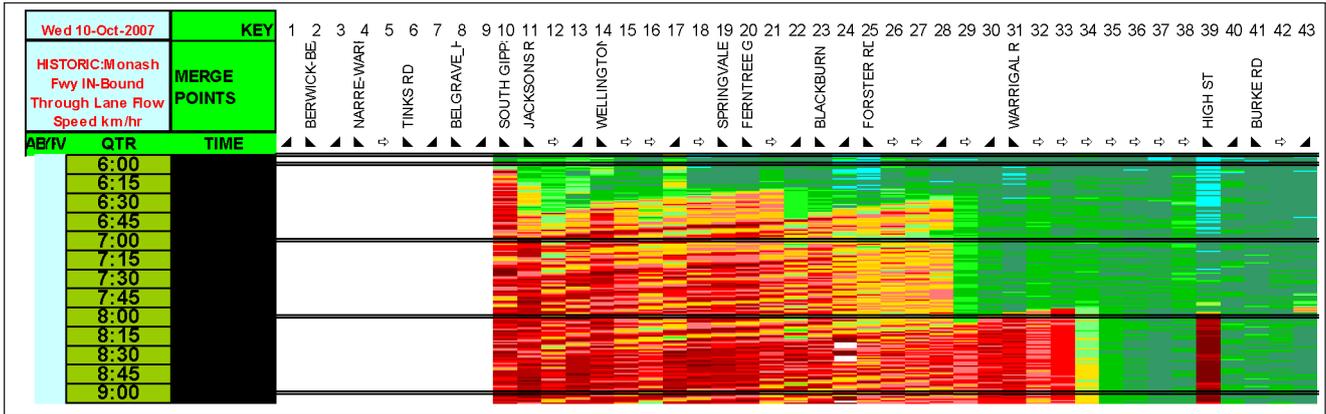


Figure A.1 Single day freeway analysis, October 2007, colour coded by speed

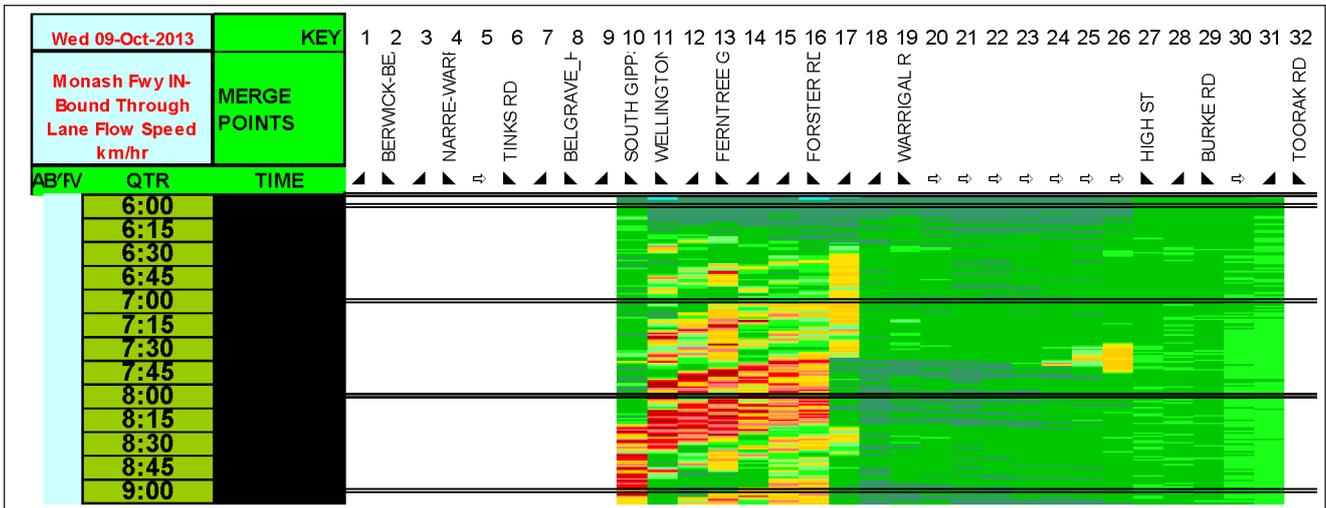


Figure A.2 Single day freeway analysis, October 2013, colour coded by speed

THRU LANE SPEED RANGES in KM/HR				
BIN	Low	High	LEGEND	INDEX
1	1	10	001 - 010	17
2	11	20	011 - 020	18
3	21	30	021 - 030	19
4	31	40	031 - 040	20
5	41	50	041 - 050	21
6	51	60	051 - 060	22
7	61	70	061 - 070	23
8	71	80	071 - 080	24
9	81	90	081 - 090	25
10	91	100	091 - 100	26
11	101	110	101 - 110	27
12	111	999	111 - 999	28

Figure A.3 Legend for colour coding

Appendix A: Further evidence of Managed Motorways benefits

Two case studies have been included within this appendix to provide discussion in more detail on the results of post-implementation evaluation of the M1 Upgrade in Melbourne. The two case studies provided have been produced to focus on only those benefits attributable to different active management tools as the general post-project evaluation of the M1 Upgrade covered the benefits of all parts of the M1 Upgrade, including the extensive civil works.

A.1 Monash Freeway before and after coordinated ramp signals

A.1.1 Introduction

This case study provides a comparison of traffic performance and road safety on the Monash Freeway before and after the upgrade of the corridor from three to four lanes and the introduction of coordinated ramp signals (CRS).

A.1.2 Background

In the before case analysis, the Monash Freeway had a generally three lane carriageway cross-section over the 25.5 kilometres study section, beginning from the South Gippsland Freeway merge and finishing at Toorak Road. There was a fourth lane between High Street and Toorak Road with six inbound SCATS ramp signal sites and three outbound sites.

The after case analysis spans the same section and is of a generally four lane cross-section with a five lane section between Toorak Road and High Street with most entry ramps metered using the HERO LIVE algorithms.

There was a total of 13 interchanges along the corridor in the before case and 14 in the after case due to the addition of interchanges with the EastLink tollway in late June 2008.

As you add more lanes to a freeway there is an expected reduction in lane capacity, primarily due to the increased number of lane changes movements possible on four lane versus a three lane freeway. Although this effect works to reduce lane flows in the after case despite this we have seen considerable uplift in performance.

The highest 24 hour weekday volumes on the Monash Freeway occurs in the section between Huntingdale Road and Stephensons Road and is typically 210,000 vehicles today (October 2013 average) with four lanes, compared to typically 160,000 vehicles (October 2007 average) with three lanes. This indicates that despite the fact that the total 24 hour flows have increased due to traffic growth and the addition of a new lane, the average 24 hour volume per lane (in the order of 26,000 vehicles per lane) has also increased due to the expansion of the peak period and increased levels of efficiency, reliability and resilience as a result of the Monash Freeway becoming a Managed Motorway. Therefore, Monash Freeway has similar lane flows over the day now as was the before case which is reflected by the extra 50,000 veh/day. It should be highlighted that 210,000+ veh/day including up to 15% commercial vehicles is a very good outcome for an eight lane motorway. This motorway still has considerable room for growth through the day with some peak day volumes already around 220,000 between Huntingdale Road and Stephensons Road (as at October 2013).

Due to the changes in cross-section between 2007 and 2013, the traffic volumes have been converted to 'per lane' flows to enable direct before and after analysis of results. Heat plots are included in Figures A.1 and A.2 to demonstrate visually the marked improvement in speeds between the after and before case.

A.1.3 Results - analysis of the inbound direction

Table A.1 shows average throughputs and speeds from October 2007 (before the works) and October 2013 (after the works). As noted earlier, traffic volumes have been converted to 'per lane' flows to enable direct before and after analysis of results.

Table A.1 Inbound changes in average throughput and speed, AM peak

	2007	2013	Increase	
Average throughput – veh/h/lane	1,476	1,755	279	19%
Average speed – km/h	63	75	12	19%

In the inbound direction in October 2007, during the peak AM period of 6am to 9am, average volumes per hour per lane were 1,476 with average speeds of 65 km/h, compared to 1,755 vehicles per hour per lane at 75 km/h in October 2013. This equates to an increase of throughput of 279 vehicles per hour per lane with an increase of average travel speeds of 12 km/h. This increase in average volumes by 279 vehicles/h/lane is a comparison of the entire carriageway for the before and after cases (additional 1,116 vehicles/h over the entire carriageway), which is significant as it means that the additional lane that has been built has been filled, and a further gain above that has occurred and is shared across

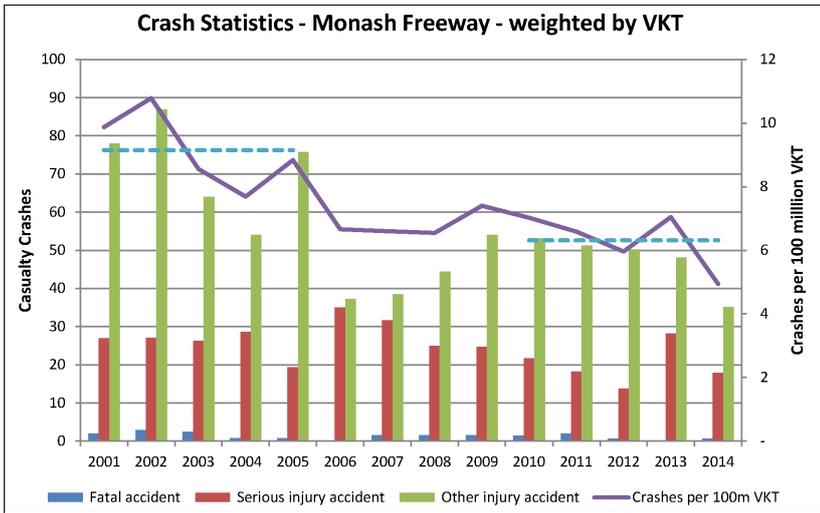


Figure A.4 Crash Statistics

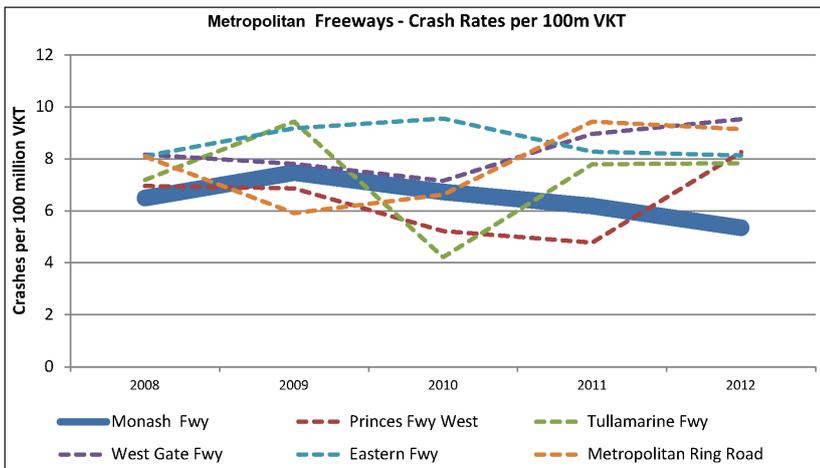


Figure A.5 Crash rates per 100 million vehicle kilometres travelled for Metropolitan Freeways

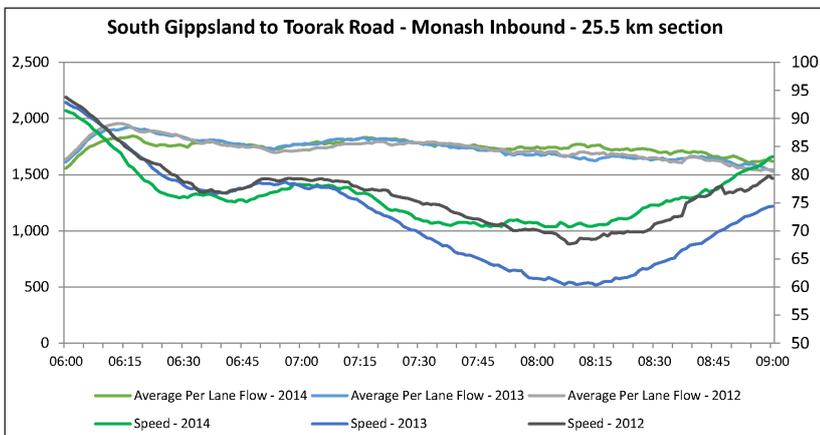


Figure A.6 Inbound performance in 2012, 2013 and 2014

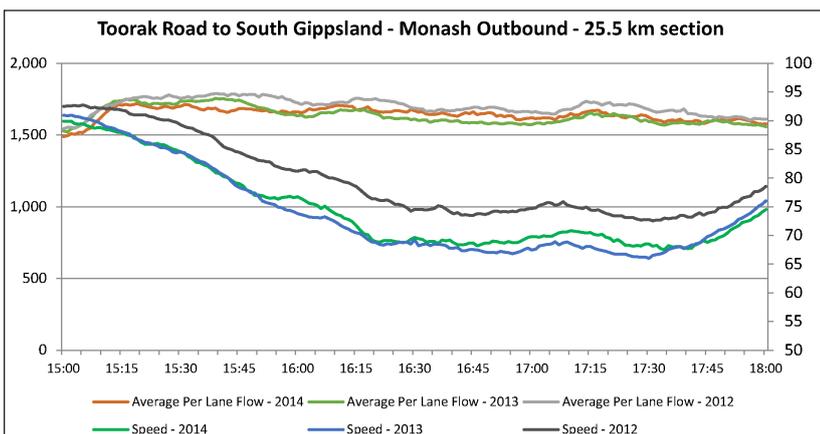


Figure A.7 Outbound performance in 2012, 2013 and 2014

all the lanes. This is indicative of the improved performance, efficiency, reliability and significant economic benefits experienced with the Monash Freeway as a result of the M1 Upgrade project and the deployment of the Managed Motorways toolkit and its ramp metering HERO LIVE.

A.1.4 Results - analysis of the outbound direction

Table A.2 shows results for the outbound direction.

Table A.2 Outbound changes in average throughput and speed, PM peak

	2007	2013	Increase	
Average throughput – veh/h/lane	1,402	1,627	225	16%
Average speed – km/h	58	74	16	28%

In the outbound direction in October 2007, during the PM peak period of 3pm to 6pm, there was approximately 1,402 veh/h/lane at average speeds of 63 km/h in October 2007, compared to 1,627 veh/h/lane at 74 km/h in October 2013. This increase in average volumes by 225 veh/h/lane is a comparison of the entire carriageway for the before and after cases (additional 900 veh/h over the entire carriageway), which is significant as it means that the additional lane that has been built has been filled, and a further gain above that has occurred and is shared across all the lanes. At the same time average speeds have increased by 16 km/h.

A.1.5 Road Safety

Road safety data has shown that the Monash Freeway (for the section between Toorak Road and South Gippsland Freeway) has had a steadily declining crash rate since completion of the M1 project. Figure A.4 shows a crash rate of 9.15 crashes per 100m VKT for the five years spanning 2001 to 2005, which precede the M1 project, compared to a crash rate of 6.31 per 100m VKT in the 5 years between 2010 and 2014 which were after the M1 Project.

Figure A.5 shows the Monash Freeway (full section, Toorak Road to Clyde Road) and its performance against the other major metropolitan freeways over the period of 2008 to 2012. Note that the Tullamarine Freeway had the completion of the Tulla-Calder Interchange Project in the year 2010.

A.1.6 Discussion

While both directions on the Monash Freeway have experienced significant benefits in efficiency through increased throughput and average speeds, there is a slight discrepancy of total vehicle throughput per hour per lane, where the outbound direction experiences only 1,627 veh/h/lane compared to 1,755 veh/h/lane for the inbound direction; a difference of 128 veh/h/lane. Generally both directions are built to the same standard with all entry ramps managed by ramp metering, with the exception of both in and outbound entry ramps from EastLink and the outbound Burnley Street entry ramp for CityLink which do not have ramp metering.

It is highly likely that this shortfall in ramp management results in uncontrolled demands entering the motorway. Where there is larger uncontrolled entry ramp demands, the more adverse the impact will be. This is case with the Burnley Street outbound entry ramp where entry ramp demands average around 1,200 veh/h for the majority of the PM peak, and it would be likely that if this ramp were to be controlled through ramp metering, that this 128 veh/h/lane discrepancy between the inbound and outbound directions could be minimised even further. Greater gains as a whole could also be achievable if both inbound and outbound EastLink entry ramps were controlled as well. This would result in the Monash Freeway having all entry ramps managed by ramp metering, as there are currently daily breakdowns in traffic flow in sections shortly downstream of the entry ramps to the Monash for both directions.

Figures A.6 and A.7 show inbound and outbound average speed and per lane flows measured over the entire 25.5 km section from South Gippsland Freeway to Toorak Rd for all non-school holiday weekdays in October 2012, 2013 and 2014. The Monash Freeway (per lane) flows are very consistent over the three hours over the three year period time frame and this consistency throughout the peak means that the CRS has been successful in limiting the impact that flow breakdown would have on peak flows (refer to Figure 2.4 for an example of an unmanaged motorway).

The inbound speed and volume has improved in 2014 resulting in both a later and lower peak at the start of the peak periods; this is substantially resulting from deployment of the new multiple bottleneck algorithm and additional fine tuning of parameters, which have not yet been applied fully in the outbound direction. Improving reliability was achieved by ensuring the ramp meters take control early in the peak period.

Figure A.4 shows road safety data for the Monash Freeway (between Toorak Road and South Gippsland Highway) which has had a steadily declining crash rate over the last thirteen years. It shows a crash rate of 9.15 crashes per 100m VKT for the five years spanning 2001 to 2005, which precede the M1 project, compared to a crash rate of 6.31 per 100m VKT in the 5 years between 2010 and 2014 which were after the M1 Project. In comparing the before and after case with respect to crash rates, this represents a 31% decline in the 5-year average crash rate, demonstrating the benefits of adopting the Safe System approach on the Monash Freeway.

It is then important to compare these crash statistics against other metropolitan freeways to gain an understanding of its relative performance. Figure A.5 shows how the Monash Freeway (full section spanning from Toorak Road to Clyde Road) is performing better than the other major metropolitan freeways over the period of 2008 to 2012 by having a crash rate that is in general lower than the other freeways, and is trending down at a greater rate. Note that the Tullamarine Freeway had the completion of the Tulla-Calder Interchange Project in the year 2010.

A.1.7 Conclusion

In the before case the route had nine operational isolated SCATS ramp meters controlling the route, whereas in the after case almost all except three major entrances use CRS (exceptions were East Link Ramps both directions and Burnley Ramp) operated via HERO LIVE software.

Besides ramp signals there were no other controlling ITS tools implemented on this 25.5 km route. It is apparent from the analysis (summarised in Figure A.6) that CRS alone enabled the inbound on Monash Freeway to achieve near capacity flow of 1,755 veh/h/lane (+19%) throughout for the entire peak period 6:00 to 9:00 am with considerable improvement in speed (+19%) compared to the before case. The outbound performance was also greatly improved (+16% in throughput and +28% in speed), but would have benefited more from having the Burnley Ramp Meter switched-on to enable an equivalent comparison of both directions. The 2014 October traffic volumes have also remained steady with similar lane flows.

Another performance measure built into the M1 Upgrade Business Case was to increase peak hour throughput by 50%, although only by adding one lane which was expected to increase throughput by 33% together with the CRS that was expected to deliver the remaining 17%. In retrospect there is now additional understanding of a general relationship between number of lanes and lanes flows and it have observed on Melbourne freeway network that as you add lanes to a freeway the actual per lane flows decrease, primarily due to the increased turbulence resulting from additional lane changing. Hence, the 33% should have been assumed to be closer to 25%. The results in this case study show that despite the over-estimation of the capacity increase as a result of the extra lane, the peak hour flows for the freeway section South Gippsland Freeway to Toorak Rd have increased on average by 56%; this is made up of an increase of 59% in the inbound direction during 6:00-9:00am and 54% in the outbound direction at 3:00-6:00pm, clearly demonstrating the benefits of CRS.

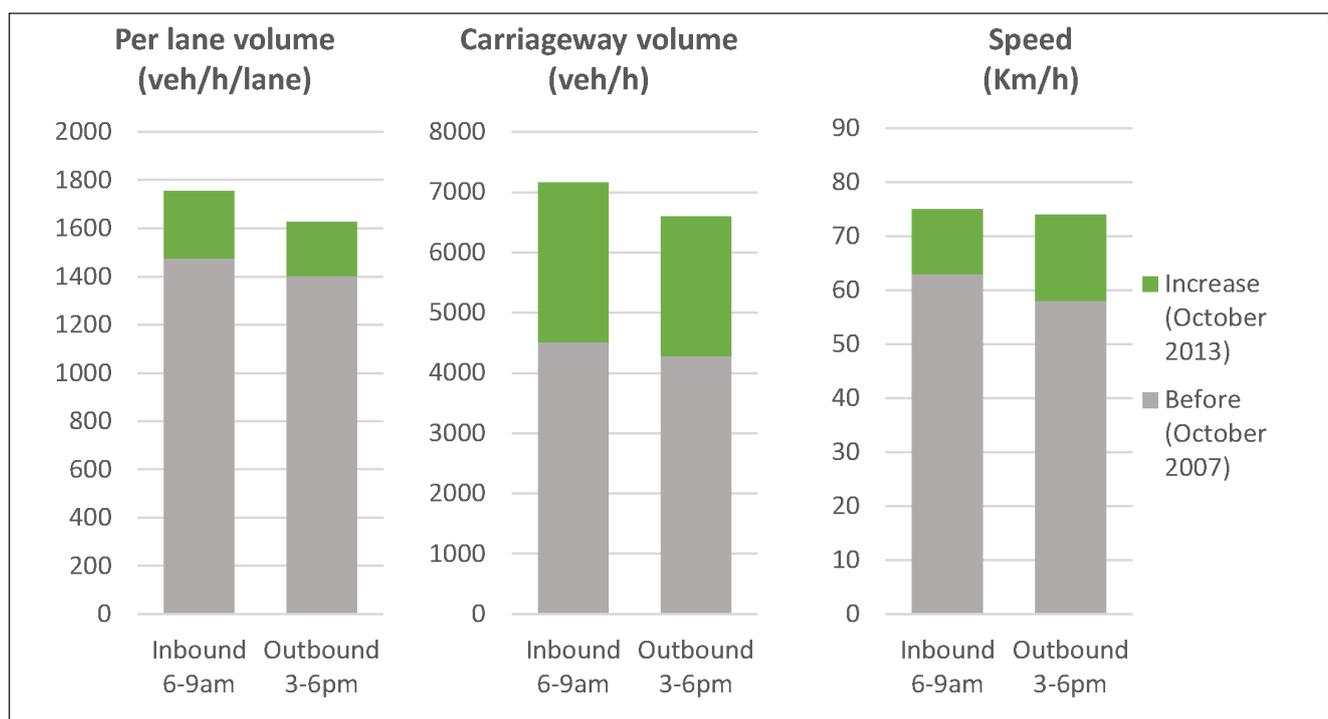


Figure A.8 Summary of increases in speed and per lane and carriageway volumes

In addition, a separate study of crashes notes for a similar section of freeway, e.g. Glenferrie Rd to Heatherton Rd), has seen the crash rates per 100 million vehicle kilometres travelled reduce between 24 and 29% over the three years since opening.

In conclusion the increased levels of efficiency, reliability and resilience as a direct result of the Monash Freeway becoming a Managed Motorway far outweighs the cost of deployment and also clearly achieves the flow and safety targets set out in the M1 Upgrade Business Case.

Ramp metering studies that report traffic volumes only at selected motorway locations and for selected days should always be closer examined as often fixing a known bottleneck will just translate the bottleneck further downstream. In some cases this might be an acceptable solution to a road authority if the bottleneck is moved downstream to a less critical location, e.g. downstream of a major freeway exit freeing increasing the exit ramp flow. However, what had been historically observed in Melbourne was just the bottleneck moving a kilometre or two downstream and offering no significant overall route or network benefit that enables the motorway to service more trips/hour and increases the outflow out of the motorway network.

The primary measure of the efficiency of any motorway system is the outflow from that system as measured at the exit ramps. In the past, too much focus of motorways has been on the entry ramps and the merge areas (the inflows). Motorway optimisation is about getting more productivity out of the motorway as a connected system.

This is the fundamental reason why in 2007 VicRoads chose a unique approach to Managed Motorways and in this report is quoting motorway per lane flows measured over all lanes all days of the month including incident days over a distance of 25.5 km which includes 14 interchanges. Optimisation is also about reliability and hence should be consistent from day-to-day, month-to-month and year-to-year as shown in Section A.1.5 above.

A.1.8 Opportunity for further performance improvement

There is still opportunity for further performance improvement and the evaluation undertaken for this study has revealed that the Monash Freeway route would benefit from further detailed analysis and fine tuning of control parameters as many of the new features of HERO LIVE are yet to be implemented.

A.2 All lane running (ALR) with integrated speed and lane use management

The term 'All Lane Running' (ALR) refers to the use of the full pavement width on a freeway for full time use by traffic without a continuous emergency stopping lane. This term has been adopted for this case study to maximise international consistency, although it should be noted that the term was not used as part of the M1 Upgrade and the implementation example studied here pre-dates the now extensive UK development activities and rollout currently in progress for ALR schemes.

A.2.1 Introduction

The West Gate Bridge in 2007 was a four by four lane bridge plagued with many hours of congested slow moving traffic. This critical transport asset for Melbourne is worth several billion dollars and is a key access and freight route for the city, and widening it or building an alternative river crossing had proven to be an unaffordable prospect at the time. This case study assesses the increased productivity of the West Gate Bridge as an example of how active management using ITS enabled the exploitation of greater productivity from a critical piece of infrastructure, with only minor additional civil works on the structure itself. It was recognised at the time that the economic value gained from the additional lane and strengthening works on the bridge included the extra years of traffic demand that could be met by bridge in the years until the State could afford to build another crossing of the Yarra River.

It is acknowledged that there were complementary civil works east of the bridge on the inbound direction, which were undertaken to remove significant bottlenecks and weaving areas further east, and these could contribute to the additional uplift in flows. However, no additional works were undertaken in west of the bridge the westbound direction as the bottlenecks were only on approach to the bridge, and this direction has also seen similar uplift in daily flows. The additional lanes on the bridge are now able to service some 1700+ veh/h in both directions.

After the works were completed, in 2013 the West Gate Bridge carried an average of 202,000 vehicles daily between Tuesdays and Thursdays, which is an additional 40,000+ vehicles per day (>25% increase) compared with 2007 figures, and there remains potential for daily traffic volumes to grow further using the capacity for growth in the counter peak direction. In the morning 6:00 am to 9:00 am peak, the bridge now carries an additional 5,616 vehicles (+27%) and during the evening peak an additional 5,800 (+26%) vehicles cross the bridge between 3:30 pm-6:30 pm as a result of the extra lane and active management systems.

A.2.2 Background

In 2004 to 2005, several papers were presented to VicRoads' Project Review Committee (PRC) to develop new ways to exploit freeway reservations to reduce congestion and improve efficiency and capacity by introducing treatments such as Managed Motorways through CRS, emergency lane running (part-time), reversible lanes and contraflow operations.

In particular, it was shown to PRC at the time that:

- VicRoads was not managing our freeway road assets to their full potential and hence losing up to 20% of potential operational capability and;
- Even though VicRoads had significant investment in various ITS, they were not working together as a system to maximise the asset's performance.

Subsequently and based on approval by PRC, a business case was accepted to introduce a contraflow arrangement on the West Gate Bridge to five lanes in the peak direction and three lanes in the counter peak, in order to maximise the productivity of this important asset for Melbourne. The PRC project recommendations that were approved included the following comments:

- 'PRC approve a detailed investigation into increasing the capacity of the West Gate Freeway between the Western Ring Road and Todd Road. This will include shoulder lane treatment between the Western Ring Road interchange and Williamstown Road and contraflow lane treatment between Williamstown Road and Todd Road'; and
- 'PRC approve the development of a business cases to build flexibility into the management of new freeway cross-sections including the use of contraflow and reversible lanes.'

At the time, the West Gate Bridge was operating well beyond its original design capacity and it was foreseen that it would be many years before the State could afford and build another lower crossing of the Yarra River. The general intent of the PRC paper in regards to the West Gate Bridge was that the introduction of an alternative operational regime could service more vehicles per day. Although the reduction to three lanes for the counter peak direction would increase congestion in that direction, the improvements in the peak direction still provided a net benefit.

Extending the usefulness of this major bridge asset would buy the State valuable time before a second Yarra River crossing could be built. At the time, it was estimated that around 1,500 additional vehicles per hour could be serviced in the peak period.

Although the solutions ultimately adopted vary from those approved by PRC at that time, this approval within VicRoads was an important step in setting the direction for more active management of Melbourne's freeways using ITS and set in motion Australia's first significant Managed Motorway project. Major bridges in the region already had well-established reversible lane regimes (e.g. Auckland Harbour Bridge and Sydney Harbour Bridge), however the broader route treatment including optimisation along the route were significant features of the Melbourne proposal at that time.

A.2.3 M1 Upgrade project

Within months of the beginning of preliminary concept and design work, the project captured the attention of the Victorian government and discussions were initiated with Melbourne's toll operator Transurban who also understood the potential of using ITS to increase the physical and operational capacity of the freeway. In a short period of time, in collaboration with Transurban, the Monash-City Link-West Gate Upgrade Project (M1 Upgrade) was developed with the project commencing in 2007.

The M1 Upgrade project scope initially included:

- Developing a Freeway Management System (FMS) to optimise the route (which also included the CRS functionality discussed in Section A.1);
- Introducing a contra-flow arrangement to the West Gate Bridge, (retaining the 4+4 lane configuration off peak, and introducing 5+3 lanes during peaks);
- Adding an additional lane between South Gippsland Freeway and east of the West Gate Bridge;
- Converting emergency stopping lanes to running lanes on the inner freeway sections between Toorak Road and West Gate Bridge; and
- Addressing traffic weaving issues on the West Gate Freeway with braided solutions and collector distributor carriageways.

As development work on the project continued, it was recognised that the proposed contraflow arrangement for the West Gate Bridge introduced significant operational complexities and costs particularly as the cross-section of the bridge required two reversible single lanes, each with barrier separation but no room for shoulders (emergency lanes) for those single lanes. For this reason, as well as the congestion in the counter-peak direction created by the reduction to three lanes, the project team worked with the West Gate Bridge Strengthening project team to consider alternative approaches.

Through this collaborative approach, VicRoads was able to achieve superior outcomes by strengthening the bridge's outer shoulders so that they could be used for general purpose lanes carrying all traffic, including large trucks. This was no small achievement given the structural form of the bridge having these shoulders as the relatively weakest part of the structure.

This combination of integrated Speed and Lane Use Management (LUMS) and slightly narrowed lanes allowed for a five by five lane operation (compared to four by four lanes before). This was complimented by the broader route management approach that included other ITS tools such as CRS to provide a safe and operationally efficient solution (refer to Section A.1).

A.2.4 Results

Table A.3 summarises the before and after results in terms of daily 24 hour flows and includes mid-week, Tuesday, Wednesday and Thursday data for the month of October 2007 compared with October 2013. The West Gate Bridge is now carrying +41,284 more vehicles per day with the average lane flows over the days in 2013 being slightly higher (40,446) than in 2007 (40,262). This means that the vehicle throughput of the bridge has increased by 1.26 times that compared to the initial demand, keeping in mind that the nominal lane capacity provided has increased by a multiple of something less than 1.25 as although five lanes replaced four lanes, the lanes are now narrower and shoulders have been significantly reduced.

Table A.3 Before (2007) and after (2013) West Gate Bridge daily traffic volumes

	October 2007	October 2013	Increase	
Number of lanes (x carriageway)	4 (x2)	5 (x2)	1 (x2)	25%
Average daily volume (veh, midweek)	161,046	202,330	41,284	25.6%
Average daily volume per lane (veh/lane)	20,131	20,233	102	0.5%
Average daily volume Inbound	79,879	98,106	18,227	23%
Average daily volume Outbound	81,166	104,224	23,058	28%

From Table A.4 it can be seen that the inbound direction shows only a modest 2% increase in per-lane flows, however the total three hour (6:00-9:00 am) flow for the bridge has increased by 5,616 vehicles (three hours of 1,872 per hour).

Table A.4 Results for 6:00 to 9:00 am inbound, midweek

	October 2007	October 2013	Increase	
Average peak volume per lane	1,705	1,739	34	2.0%
Average peak volume per carriageway	6,822	8,694	1,872	27.0%
Average speed (km/h)	52.1	58.6	6.5	12.6%

From Table A.5 it can be seen that the outbound direction shows only a modest 1.1% increase in per-lane flows, however the total three hour (3:30-6:30 pm) flow for the bridge has increased by 5,800 vehicles (three hours of 1,933 per hour).

Table A.5 Results for 3:30 to 6:30 pm outbound, midweek

	October 2007	October 2013	Increase	
Average peak volume per lane	1,830	1,850	20	1.1%
Average peak volume per carriageway	7,316	9,249	1,933	26.4%
Average speed (km/h)	65.9	54.7	-11.2	-17.0%

The combined, inbound and outbound peak one hour throughput of the West Gate Bridge has increased by 22% (see Table A.6). This peak one hour is located between 7:00 to 8:00 am. During the M1 Upgrade's PRC report in 2004, the projected peak volume was expected to reach 15,000 in 2015, which has already been exceeded in October 2013. Despite this, there is still room for additional growth in this figure as there is still capacity for growth in the counter peak direction (outbound).

Table A.6 Results for 7:00 to 8:00 am both directions, midweek

	October 2007	October 2013	Increase	
Average one hour volume	12,527	15,283	2,756	22.0%

A.2.5 Conclusion

The West Gate Bridge case study is an example of how innovative thinking and active management are capable of unlocking the maximum potential from road infrastructure. Benefits delivered as examined in the prior sections include:

- Increased flow rates on a per lane basis;
- Increased carriageway flow rates; and
- General improvements to average travel speeds.

Outcomes in these areas are better than what could have been achieved through the addition of traffic lanes without active management.

A.3 International evidence of benefits

Table A.7 provides international examples of benefits from a variety of Managed Motorways tools.

Table A.7 Examples of benefits from international applications of Managed Motorways tools

Outcome area	Summary	Ramp Signalling	All Lane Running / Hard Shoulder Running	LUMS/Dynamic Speed Limits with supporting Traveller Information
Capacity / throughput	Capacity increases of 5-22% Throughput improvement generally 1-20% (some cases up to 74%)	Qld M1/M3: 4% increase in AM peak inbound throughput (slight increase in flow of 150 veh/h that was sustained throughout the peak period). Average AM peak in bound travel productivity has improved by 8% Vic M1 (CRS): improvement of 19% on a per lane basis Minneapolis St Paul: decrease in travel volumes by 9% when ramps switched off Other US cities: 18-74% increase in peak volume	UK M42: increase of 7-9% with HSR Munich: 20% increase in rush hour capacity Netherlands: 7-22% increase capacity and up to 7% increase in travel volumes	UK M25: 15% increase in throughput over 5 peak hour periods, reduction in AM peak shockwaves from 7 to 5 Germany: 5-10% improvement in capacity Netherlands (VMS): increase in throughput of 4-5%, France A7 (VSL): 10% increase in peak period flow and 16% reduction in congestion
Reliability	Reliability improvements of 10-60%	Vic M1 (CRS): travel time reliability improved by 4% up to 20% in peak periods Qld M1/M3 Qld (CRS): 37% improvement in 'good' reliability for AM peak (over 50% now receive reliable travel).	UK M42: reduction in journey time variability of 22-32% (27% on weekdays)	Tasman Highway (VSL) – 60% reduction in travel time variability in peak hour
Safety	Crash reductions highly variable, generally from 10 – 50% depending on level of severity/ time period	Vic M1 (CRS): 12% reduction in crashes, 19% reduction in fatal crashes and 10% reduction in serious/other crashes (based on 2.5 year ex-post data) Minneapolis St Paul: 26% increase in crashes during eight week period when ramps switched off US (various): 15-50% reduction in peak period collisions (in one state, up to 71% reduction in injury collisions)	UK M42 – up to 56% reduction in personal injury accidents and reduction in accident severity index from 0.16 to 0.07	UK M25 (VSL): 10% reduction in injury accidents and 20% reduction in damage only accidents A5 Germany (VSL): 30% reduction in personal injury accidents, 27% reduction in heavy material damage accidents Bavaria, Germany (VSL): accidents reduced by up to 35%, with 31% reduction in crashes involving injury The Netherlands A13 – 50% reduction in accidents Other Dutch projects (VMS, VSL): 15-25% decrease in primary accidents and 40-50% decrease in secondary accidents (1983-96) Adelaide Crafters Highway (VSL): 24% crash reduction in first 12 months NSW M4 (VSL) – total crash reduction by 11%
Speed / travel time (during congestion)	More variable – generally there are improvements some instances of overall reduced speeds leading but leading to improved travel times	Vic M1 (CRS): 33% improvement (25km/h) in peak period inbound travel times on fully managed section Qld M1/M3 (CRS): 7% increase in travel speeds (AM peak) from 70 to 75 km/h. Also 8% improvement in travel efficiency (with average speed within 30% of speed limit) Minneapolis St Paul (CRS): speeds reduced by 14% but resulting in improved travel times	UK M42: reduction of peak hour journey times of 9-24%, (but also reported increase in travel times overall) The Netherlands: decrease in travel time of one to three minutes	Seattle I-5 – 4-31% travel time reduction during congestion Stockholm – up to 30% reduction in travel times during recurrent congestion (and 9% during congestion caused by incidents) NSW F3 (VSL) – 2.5-20% travel time reduction during peak hours (best estimate 8%) Tasman Highway (VSL) – 15% travel time reduction during morning peak I-270/I-255 St Louis (VSL) – up to 27% reduction in travel times with up to 10% decrease in average travel speed during peak hours M4 NSW (VSL) – negative impact on spot speed but improved speed compliance

Appendix B: Managing multiple active LUMS requests

Where a lane use management system (LUMS), including variable speed limits (VSL), is implemented, there are numerous reasons for the implementation of a change in speed limit or lane closure. LUMS display changes can be configured to happen automatically, some with operator confirmation and others are manually requested by an operator. This section describes the current and proposed future LUMS request architecture and high-level operation of LUMS and related subsystems.

When multiple dynamic LUMS response algorithms are configured, it is possible that more than one simultaneous LUMS request may be generated. For example, high winds in an area may cause a drop in speed and the presence of a queue may activate the queue protection function to create a speed reduction buffer. In addition, the use of the system by multiple operators may also result in additional simultaneous requests. Where these requests overlap on the road (or are in close proximity), the system must merge these requests into a single LUMS response plan for the affected sections of the network. The rules governing how these requests are merged are implemented in the logic of the system.

Before the merged response plan is implemented, however, it is further updated to ensure it is compliant with the rules governing the lane closures and speed limit changes. These rules are discussed in more detail in Section 4.4.1 and the Managed Freeways Handbook for LUMS, VSL and Traveller information (VicRoads 2013d).

B.1 Current operational architecture

B.1.1 Introduction

The control architecture of the LUMS subsystem and associated components is shown in Figure B.1.

Each of the components shown in Figure B.1 is described in more detail the following sections. For a full explanation of the system components, please refer to the LUMS Specifications and LUMS Concept of Operations.

As discussed in section 4.4.2, VicRoads has no plans to use the current High Flow algorithm that exists in Queensland at present. Alternative algorithms may be developed in future to provide complimentary functionality in line with VicRoads approach to motorway optimisation.

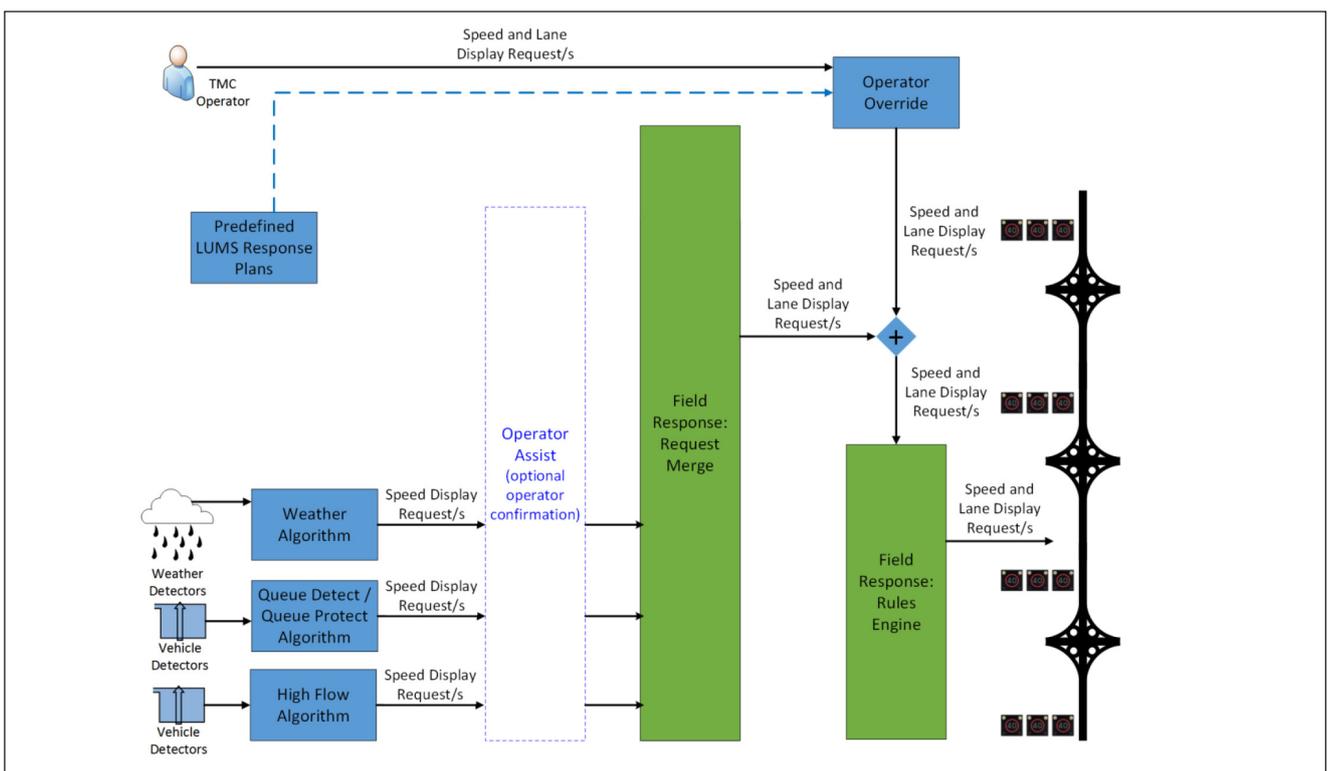


Figure B.1 Implied LUMS architecture

B.1.2 Weather algorithm

A weather algorithm would allow the VSL system to be configured to respond to changing weather. The conditions under which the system could respond to include:

- **Rain:** Includes a light rain response and heavy rain response. Detecting a rain event of a particular magnitude, reducing speed limits and providing supportive messages via VMS will assist safe operations.
- **Wind:** Includes a high wind speed reduction response when the wind exceeds the configurable wind threshold for a specified time period.
- **Visibility:** Includes the ability to reduce the speed limit in response to fog or smoke. The speed can be reduced incrementally in response to different levels of visibility and be restored as visibility improves.
- **Surface Friction:** Includes the ability to reduce the speed limit in response to changes in the co-efficient of friction due to rain, snow or other factors.

Each weather sensor has a defined zone of influence within which the speed change requests will be activated.

B.1.3 Pre-Defined Response Plans

Pre-Defined Response Plans allow the operator to save a set of LUMS speed and lane control displays for activation when needed later. Typically, these response plans are associated with a specific combination of one or more lane closures. They are created and activated using the LUMS Schematic when Traffic Event Manager is activated. This feature has been used by VicRoads for a number of years.

B.1.4 Field Response: Request Merge

The Field Response Request Merge function implements the following hierarchy (from highest to lowest) when merging requests on a sign:

1. Lane closed display
2. Lane closing display (flashing X or merge arrow, depending on state)
3. Exit arrow display
4. Speed display (where the lowest speed request is the highest priority speed request).

B.1.5 Operator Override Request

The Operator Override Request is similar to the Manual Operator Request, except that it is not merged with any existing or future responses; instead it overrides any existing display request. This allows an operator override to raise an existing speed limit or open a closed lane.

As shown in the existing architecture diagram (Figure B.1), an operator override is overlaid over the merged request before being submitted to the Rules Engine.

B.1.6 Field Response: Rules Engine

Table B.1 lists the rules defined for the field response service which implements most of the rules in the Field Response Rules Engine. Three types of rules are available in the system:

- **Fundamental Rules** are rules which cannot be bypassed by operators. The operator must modify the LUMS response plan before the system will allow it to be implemented. For example, a change of speed to a mainline LUMS will cause a corresponding change to the speed on an on-ramp VSL that feeds traffic to the same freeway segment.
- **Recommendation Rules** are policy rules and these may vary between states. An operator is warned when a requested LUMS response contradicts one or more of these rules. The operator may either modify the response plan to comply with these rules or may bypass the warning and proceed to implement the plan. All recommendation rule bypasses are logged by the system.
- **System Rules** are automatic rules that speed up the implementation of LUMS plans. For example, the system may require that any non-default speed showing on a LUMS is accompanied by a flashing annulus. Having this rule enabled reduces the work required by an operator.

The final column indicates which rules are enabled in Victoria and Queensland and have been colour coded for ease of reference. Pink is used if it has only been implemented in Queensland (QLD), blue if it has only been enabled in Victoria (Vic), white if it has been enabled in both and grey if it is not enabled in either state.

Table B.1 Indictive LUMS Field Response rules

Field Response Rule	Type	Description
Add Lane Closure	Recommendation	LUMS Sites in an Add Lane should only be closed when the Add Lane is one of the affected lanes. However, if the Add Lane is surrounded by closures (upstream, downstream, and adjacent lane) with no access to an exit ramp, a closure will also be recommended.
Annulus Flash	System	The annulus around a speed limit will be made to flash whenever the posted speed limit is changed to non-default speed.
Decreasing Speed Buffer (By Default Speed)	Recommendation	The maximum speed difference a site may display in relation to the next non-blank upstream site when decreasing the site's speed. The value used will depend on the default speed limit of the site.
Decreasing Speed Buffer (multiples of 20km/h preferred)	Recommendation	The speed difference a site may display in relation to the next non-blank upstream site when decreasing the site's speed. The system will implement a speed difference of 10km/h, 20km/h, or 30km/h, with buffer sites displaying multiples of 20km/h where possible.
Device Change Validation	System	Check for display or state changes to devices in the request after the response was generated. Provide a warning to the operator asking if the wish to regenerate.
Emergency Access	Recommendation	The Emergency Access rule applies when there are lane closures in a median or kerb lane. It extends the closures to the next entry ramp within the specified Maximum Propagation Distance parameter to provide emergency vehicle access to the incident. Where the lane closure request already includes an entry ramp, the kerb or median closure will not be extended to the next upstream entry ramp. Default range is 1,500 m in a range of 250-10,000 m.
Entry Ramp Merge	Fundamental	Ramp sites will always display the same speed as the surface road site directly upstream from the ramp. This rule assesses the speed for sites directly upstream on all merging approaches. It applies the lowest speed on all of these sites. The rule includes speeds from both static speed signs and speeds posted on operational LUMS sites.
Exit Ramp Closure	Recommendation	Displays the 'diagonal up arrow' where a closure extends over an exit ramp. This is displayed at the first enabled site upstream from the ramp. Set the Message ID parameter to either Exit (Left) or Exit (Right). This exit symbol will be cleared in the same transition as the closed symbols which caused the closure to extend over the exit ramp. Propagation of lane control symbols will not occur if the next upstream site is not within the distance set by the Maximum Lane Propagation Distance parameter.
Full Closure Propagation	Recommendation	All lanes in all sites will be closed upstream to the next exit ramp where a full surface road closure occurs. Normal lane closure propagation will be applied after the exit ramp. The full closure propagation of lane control symbols will not occur if the next upstream site is not within the user-specified distance.
Full Closure Validation	Recommendation	All signs at a site display closed. Provide a warning to the operator that a full closure has occurred, asking if they wish to continue.
Full Freeway Closure Speed	Recommendation	The maximum speed displayed for the sites with lane control during a full freeway closure. Where a single symbol is displayed, the parameter used depends on the default speed limit for the site. Note: the value is subtracted from the default speed.
Lane Closure Length	Recommendation	Each closed lane must have a minimum number of sites (Minimum Closure Length parameter) and must extend one site further than any closed lane toward the inside of the carriageway. There must be at least one path that meets the minimum closure length requirements. The minimum closure length does not include the site with the flashing cross (see Lane Merge rule). Where the 'Enable Lane Rule Propagation Over VSL Only sites' parameter is set to 'False', the lane closure propagation will stop at the VSL site. However if this parameter is set to 'True' the Lane Rule Propagation will only propagate speeds over these VSL only sites. Propagation of lane control symbols will not occur if the next upstream site is not within the Maximum Lane Propagation Distance.
Lane Closure Speeds (By Symbol)	Recommendation	The maximum speed displayed for sites with lane control. The speed for the furthest downstream site in the request is specified in the Furthest Downstream Site parameter. The speed for other upstream lane control sites in the request is determined based on the number of symbols to be displayed at a given site. Note: Where a single symbol is displayed, the value is subtracted from the default speed.
Lane Control Validation	System	If lane associations have not been specified and lane control symbols are requested on the site, the system notifies that the surrounding sites don't have associated lanes.

Field Response Rule	Type	Description
Multiple Lane Closure	Recommendation	Lane closures on middle lanes are extended to the nearest side of the carriageway (kerb or median). The Closure Direction parameter is used where both sides are an equivalent number of lanes from the target. When a request to close a kerb or median lane is implemented on a LUMS Site, the closure will be extended to the same side. When a request to close both the kerb and median lane is implemented on a site, this rule is not evaluated.
Opposing Merge	Recommendation	If merge symbols are pointing towards each other, the lane closure will be extended on the median side of the carriageway.
Queue Protection Rollback	System	Queue Protection Rollback is a technique used to manage site failures for Queue Protection Requests. When a failure occurs, posted speeds are propagated to the upstream site if it is displaying a higher speed. Rollback stops when the upstream site is displaying a speed that is the same as or lower than the downstream site. Rollback will not occur if any of sites upstream from the failure are displaying lane control symbols. Posted speeds are only propagated once when consecutive sites fail. This rule is only applicable if the Rollback rule is disabled.
Ramp-to-Ramp Merge	Fundamental	Ramp sites directly upstream from a point where two ramps merge will always display the same speed. This rule assesses the speed for sites directly upstream on all merging approaches. It applies the lowest speed on all of these sites. The rule includes speeds from both static speed signs and speeds posted on operational LUMS sites.
Restoring Speed Limit	Recommendation	The first site downstream from the furthest downstream site in a request should display its default speed limit, unless the next downstream site is displaying a lower speed limit. In this situation, the first site should match the second site's speed.
Secondary Closures	Recommendation	A secondary closure occurs when the target for a lane closure is specified for a site where existing lane control symbols are displayed. Lanes will be closed toward the original closure in this situation.
Settling Time	Recommendation	The period after a site's posted speed changes where no other speed changes can be made.
Traffic Event Closure	Recommendation	LUMS Sites immediately upstream from an event location should be closed for each affected lane. If the sign is not displaying the Closed Lane control symbol, a warning will be displayed.
Traffic Event Location	System	LUMS Sites immediately upstream from an event location will use the speed recommendation from the Furthest Downstream Sites parameter of the Lane Closure Speeds rule.
VMS Display for Algorithms	System	Display messages on signs to provide information about queues, weather and high flow conditions resulting in speed reductions on LUMS Sites.
VMS Validation	Recommendation	Check for surrounding VMSs when performing an operator-initiated request. All VMSs in the immediate vicinity of the affected LUMS Sites and the first VMS upstream (within the specified distance) should display a message as part of the response.
Weather Response	System	A pre-defined request is executed when certain weather conditions are met.

B.2 Proposed future LUMS concepts

The proposed future concepts in Figure B.2 shows the complete LUMS toolset as proposed. Additional explanations of components of the proposed future architecture that are still in development are provided in the following sub-sections.

B.2.1 DVSL Flow Stability and Mainline Bottleneck Management algorithm

VicRoads' current VSL applications include reducing speed limits for high winds and for events (incidents and road works) as part of LUMS.

VicRoads is developing a new Dynamic VSL (DVSL) algorithm to operate within an integrated CRS-VSL environment are proposed for the following applications:

- Flow optimisation:
 - At critical bottleneck for flow stability and increased density;
 - Mainline metering upstream of the critical bottleneck; and
- Congestion management to improve safety:
 - In congested areas;
 - At back of queues.

Data for the DVSL system will be sourced from freeway data stations along the freeway typically at 500 m spacing, as used for existing CRS and LUMS tools. Existing data treating methodologies may be used if appropriate.

VSL changes will be displayed on overhead LUMS signs or side mounted VSL signs (both typically at 500 m spacing) as well as entry signs on freeway entry ramps.

Algorithms being developed are based on sound industrial control logic and feedback from downstream conditions at the critical bottlenecks being managed. Control logic hysteresis also needs to be considered to avoid 'chattering' between thresholds.

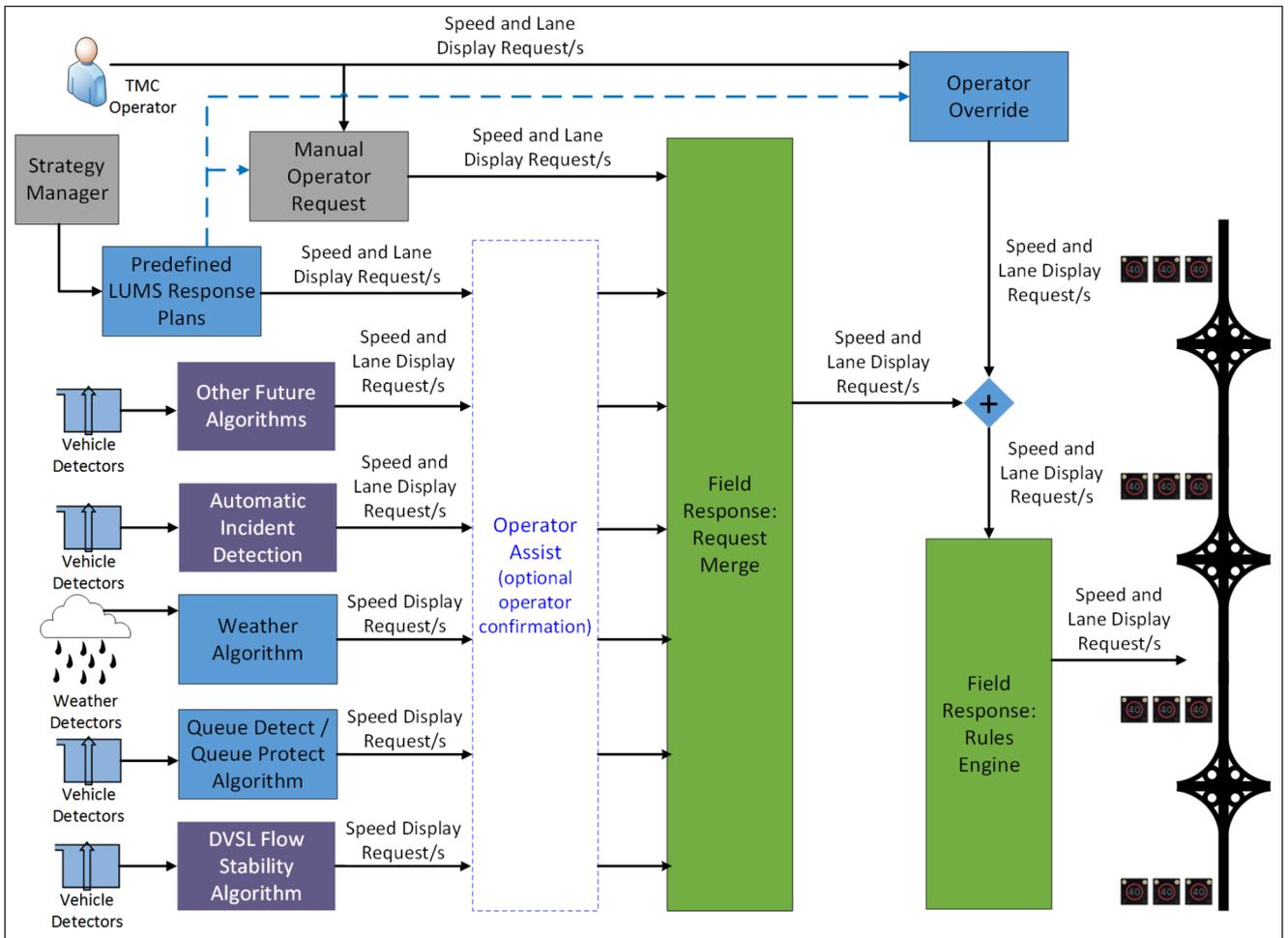


Figure B.2 Proposed LUMS architecture

The range of DVSL application in the new system is to be in configurable values between 40 km/h and 110 km/h (100 km/h maximum in Melbourne), with changes in 10 km/h increments to optimise flow. Increasing speed limits, e.g. after an incident or bottleneck, may in a single step revert back to the default speed limit if warranted by conditions, e.g., from 40 km/h to 100 km/h.

A comparison of current VSL and new DVSL applications is provided in Figure B.3.

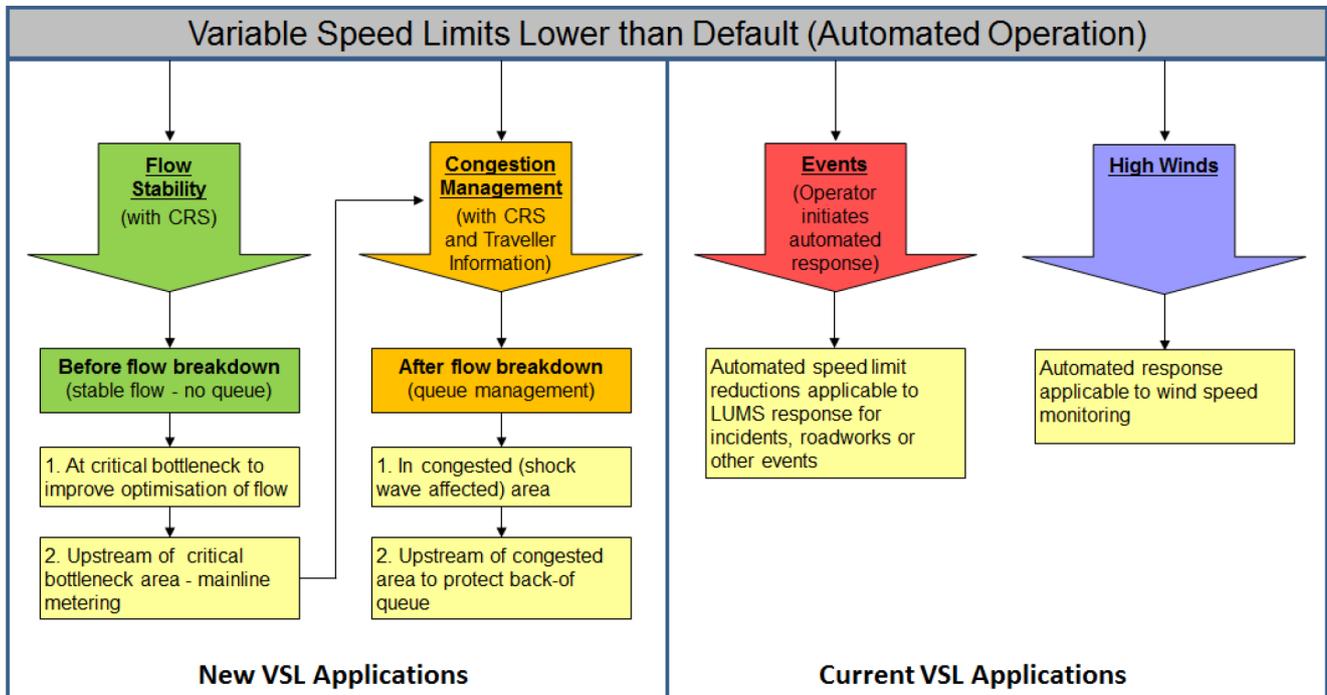


Figure B.3 Expanded functionality with DVSL algorithm

B.2.2 Strategy Manager activation of pre-defined Response Plans

Significant subject area under development by VicRoads and increasingly being used to activate pre-defined plans.

B.2.3 Manual Operator Request

The Manual Operator Request is a request initiated by a system operator using the LUMS Schematic. A typical scenario is where an operator will run the appropriate LUMS Schematic to display the current motorway conditions and any other active LUMS requests. The operator may then modify the existing LUMS displays, subject to:

- An existing speed display may only be changed to a lower speed or a lane control symbol; and
- An existing lane control display may only be changed to another lane control display.

As shown in the existing architecture diagram, a manual operator request is merged with other operator and dynamic requests before being submitted to the Rules Engine. Any future changes to the dynamic requests should be merged with the manual operator and other dynamic requests and implemented.

B.2.4 Automatic Incident Detection (AID)

Significant subject area under development by VicRoads refer Section 4.4.5.

B.3 LUMS response examples

Here we consider an example of how the LUMS system may respond to a series of LUMS requests arising from various sources. In order to illustrate the features more effectively, the case presented here is unlikely to ever occur in reality, however it provides a useful illustration.

An example freeway is shown in Figure B.4, where the weather algorithm has been triggered by rainfall to reduce the speed for an affected zone from 100 km/h to 80 km/h. Not all LUMS gantries are shown in the diagrams, so the pale green colour indicates normal freeway operation at 100 km/h.

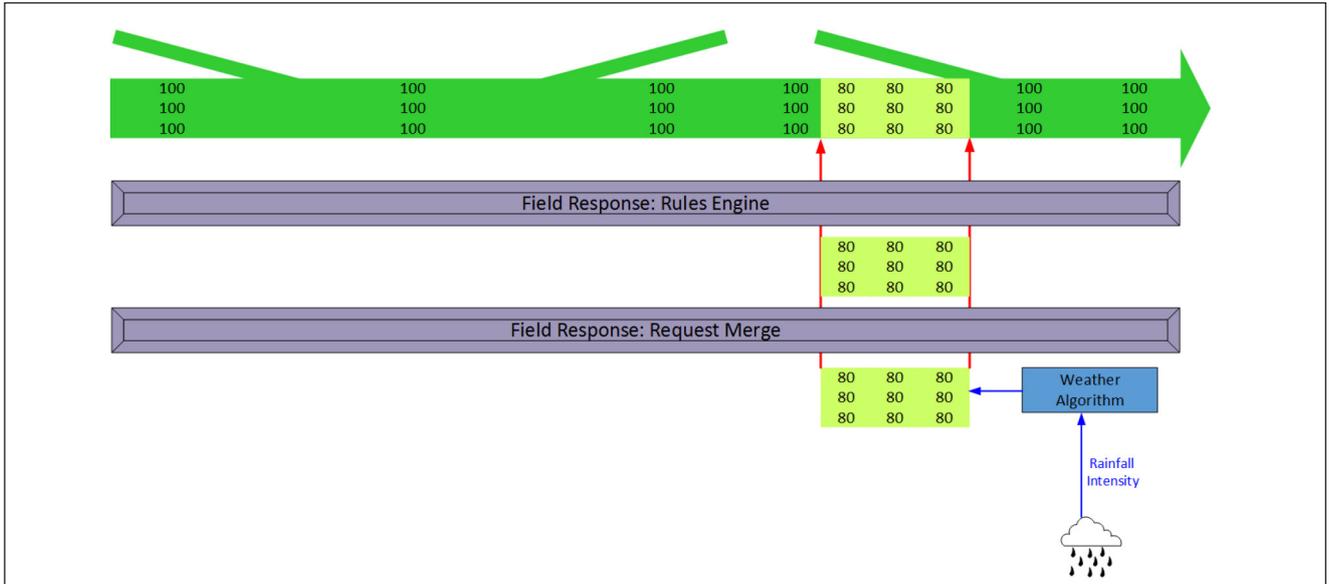


Figure B.4 LUMS example: weather algorithm triggered by rainfall

In the initial case, the Request Merge and Rules Engine do not have any specific modifications to make. However, we now introduce a Pre-Defined Response Plan just upstream of this section (refer to Figure B.5). In this case, it is shown as being automatically triggered in response to a sensor in the road that detects 'pooled water' and triggers Pre-defined Response Plan B. This response plan closes the affected right hand lane at one gantry and includes the appropriate upstream speed buffers and lane tapers.

In this instance, the Request Merge function replaces the 80 km/h weather algorithm recommendation on one gantry with the 40km/h and lane closure request of Pre-defined Response Plan B. The Rules Engine then checks the resulting merge plan and does not have to modify it in this case; however, if the upstream buffers and taper were not implemented by the pre-defined response plan, then the Rules Engine would have added them. In this instance we have shown the upstream taper implemented by lane merge arrows (illustrated in Figure B.5 via a graphical representation, not the actual LUMS display); some states use flashing crosses instead.

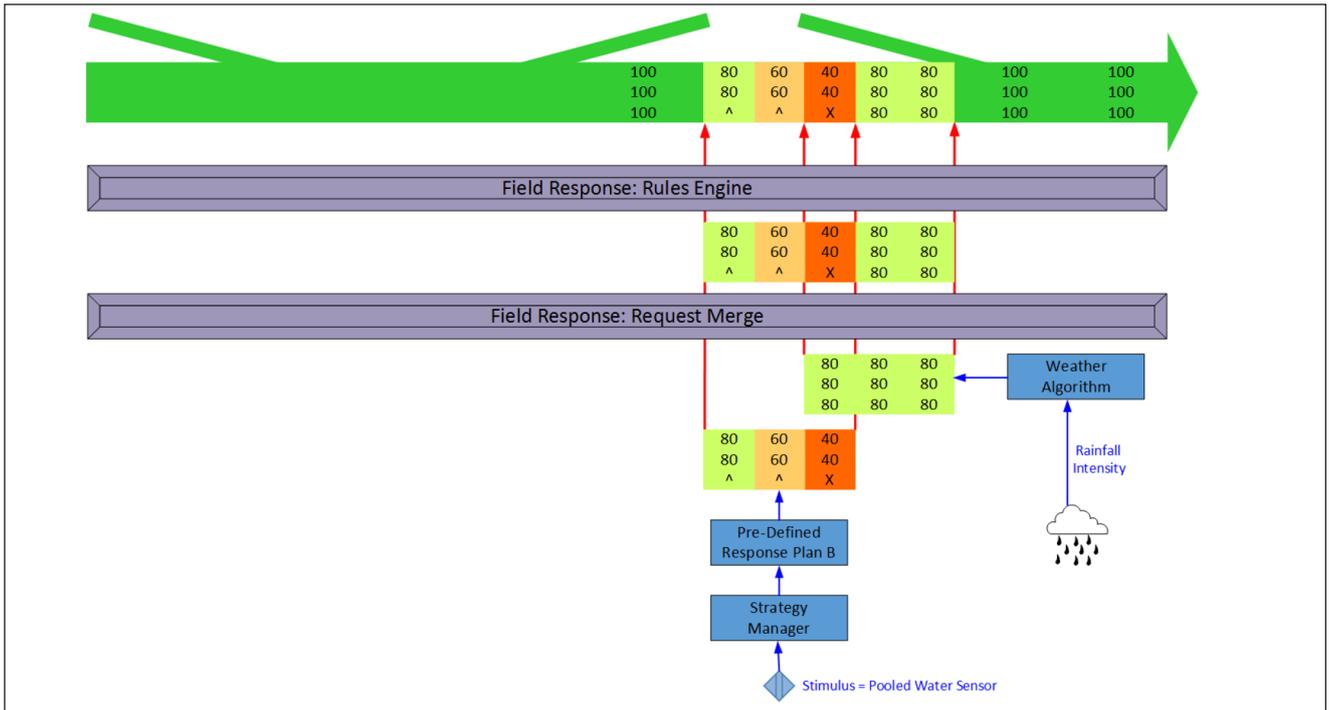


Figure B.5 LUMS example: additional request due to pooled water

If a queue subsequently forms on the freeway upstream of the water hazard and closed lane, the queue detection algorithm may then respond to protect the back of the queue (refer to Figure B.6). The most upstream 40 km/h recommendation of the QD/QP algorithm overlaps with the existing 80 km/h and Lane 3 taper, so the Request Merge implements a 40 km/h with the Lane 3 taper at this location. The Rules Engine implements the Speed Smoothing rule to replace the single 60 km/h in the merged response plan with a 40 km/h to prevent a 60 km/h section that is too short and to rationalise the number of speed limit changes.

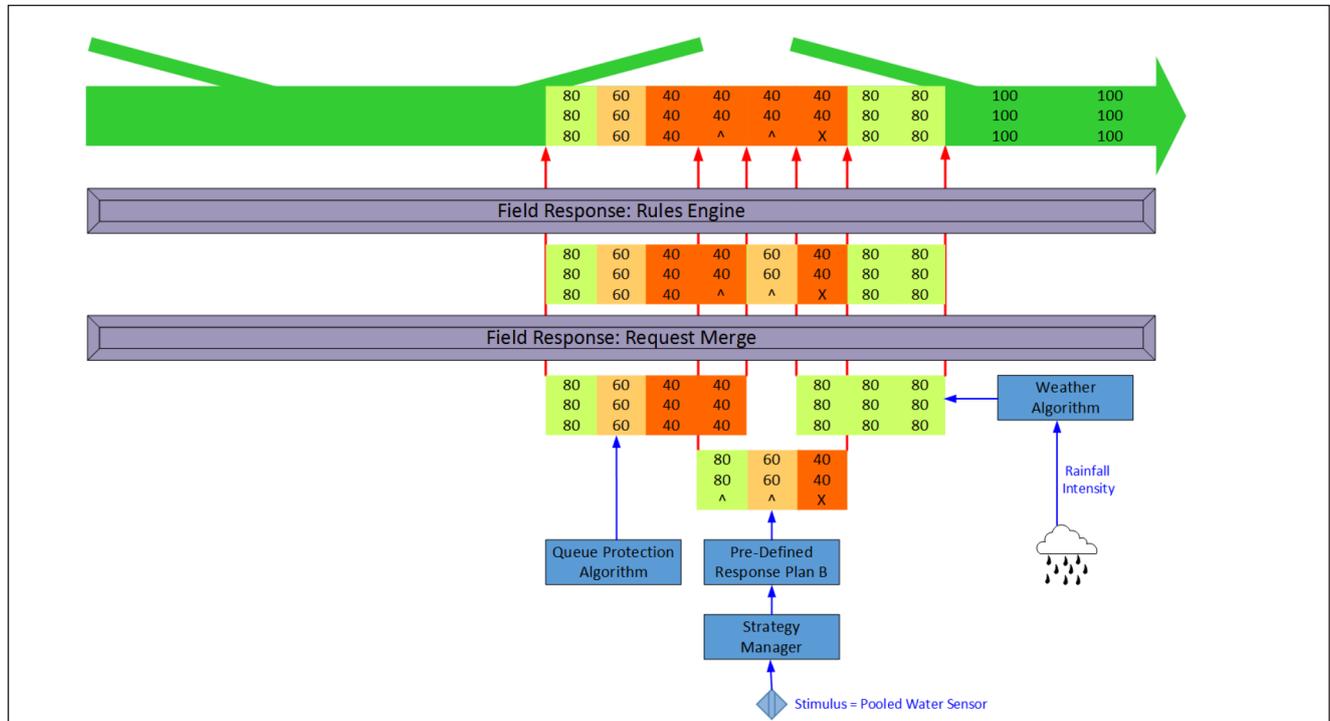


Figure B.6 LUMS example: third active request due to queue protection

Finally, if an incident occurs three gantries upstream of the existing LUMS control in Lane 1, the operator requests a closure of Lane 1 using the LUMS Schematic and then selects the 'Generate Targets' button. This requests the LUMS Schematic to use the Rules Engine to show the resulting upstream LUMS displays (refer to Figure B.7). In this instance, the Rules Engine:

- Puts 40 km/h in Lanes 2 and 3 beside the Lane 1 closure;
- Closes Lane 1 back to the preceding entry ramp to allow for emergency vehicle access to the crash;
- Puts a lane taper symbol (flashing cross or merge arrow) in Lane 1 on the gantry preceding the entry ramp to move traffic across to Lanes 2 and 3;
- Puts speed buffers in advance of the 40 km/h beside the Lane 1 closure, ensuring that the maximum speed beside a closed lane is 80 km/h.

This updated request is shown to the operator and then implemented by the operator using the 'Send' button. Upon implementation, the Rules Engine will also apply the Speed Smoothing rule to the section between the two incidents and replace the 100 km/h section with 80 km/h.

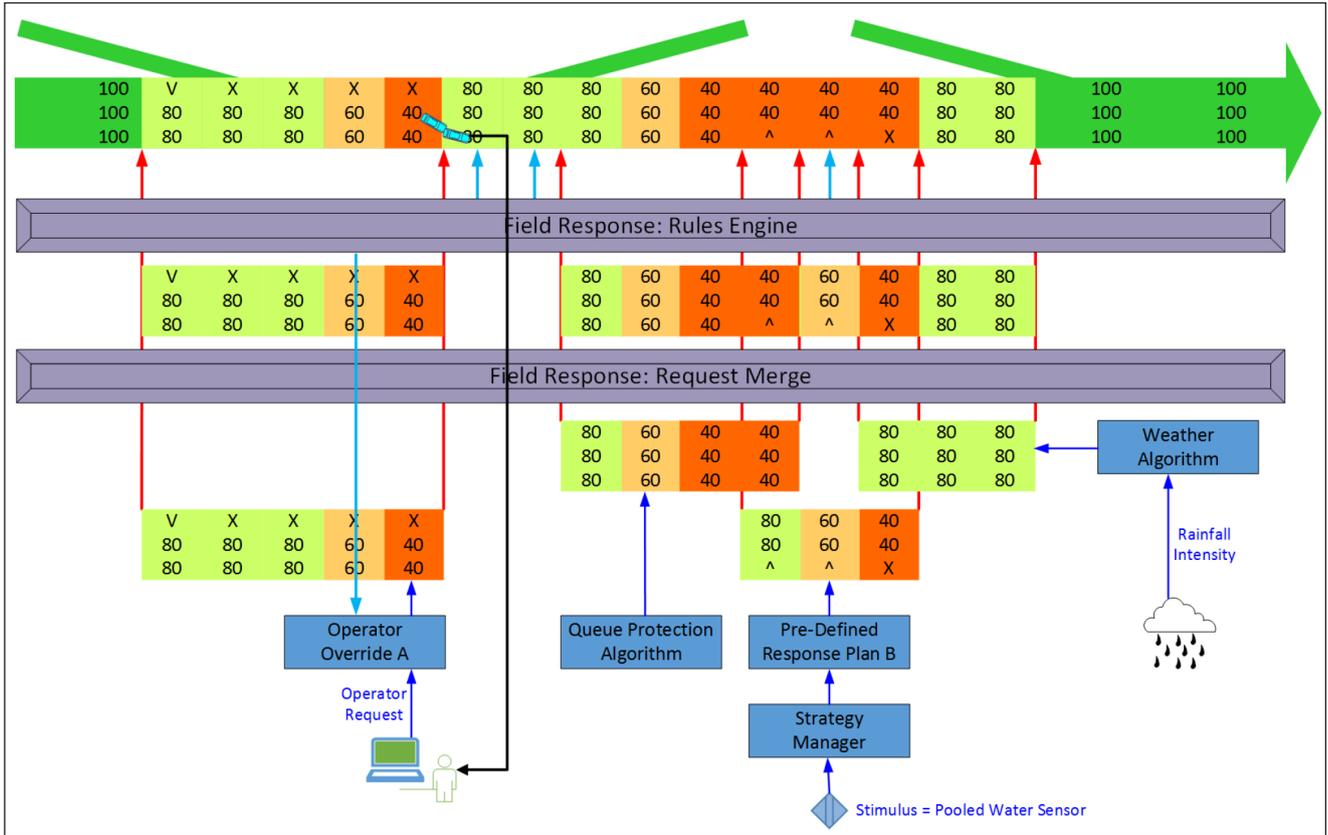


Figure B.7 LUMS example: fourth active event due to incident

Appendix C: Potential future system functionality developments

The following Managed Motorways tools are currently in development or planned for future development:

- DVSL
- Entry ramp management system
- Exit ramp management system
- Motorway dynamic re-configuration (involving entry and exit ramp management systems)
- End-of-motorway management system
- Arterial road interface management system
- Arterial road management system (with further enhancements to the arterial road interface management system)
- WAND
- External information publication for third party use
- AID
- Congestion alarms.

Table C.1 provides a consolidated list of the proposed future development of the functionalities of existing Managed Motorways tools that are already implemented on the Victorian motorway network, as identified throughout Sections 4.3 to 4.5 of this Framework.

Table C.1 Proposed future development of existing Managed Motorways tools

Tool	High-Level technical requirements
CRS	<ul style="list-style-type: none"> • Ability to switch each ramp on using multiple detector bank locations • Improved HERO LIVE coordination strategies • Layering of control using bottlenecks further downstream rather than just immediately downstream for control • Ability to detect bottlenecks at the lane level to enable early control • Ability to dynamically interpolate conditions between mainline detector banks • Extension to HERO LIVE algorithms to optimise motorways seamlessly at the network level • Updated criteria for deactivation of coordinated ramp signals to include residual ramp queue lengths in addition to mainline capacity to avoid unintended flushing of ramp queues • Improved integration between DVSL and CRS so that DVSL can support CRS in managing mainline capacity on approach to a bottleneck through a mainline metering strategy as well as assisting CRS in recovering traffic flow after breakdown has occurred
Arterial road interface Management system	<ul style="list-style-type: none"> • Modification of phase times at connecting surface road intersections to manage demand to the motorway interchange (and provide for traffic diversions) • Increased implementation of SCATS adjustments/trims through Action Lists to provide flexible, customisable control • Improved integration of SCATS and CRS to allow for more consistent actions between sites that also do not require the manual methods of Action List creation and maintenance, providing for simpler control in addition to the flexibility of Action Lists
VMS	<ul style="list-style-type: none"> • Better use of VMS at decision points on surface roads that are not in the immediate vicinity of the motorway • Modify the logic behind motorway condition information as the message is currently driven of travel time sections which are too long (e.g. 8 km) to provide accurate information at the ramp level, particularly when there is a localised incident. A conditional or statement may be required as in an incident that is near the start of a travel time section travel time can be green as once you get past the incident you can travel at the speed limit • Utilisation of other data sources for travel time information (e.g. probe data) • Improved functionality and accuracy of travel time algorithms including consideration of predictive travel time algorithms so that motorists become aware of deteriorating and improving travel conditions at the beginning and the end of peak periods respectively overcoming the current lag in real-time algorithms of up to 15 minutes • Future motorway projects to assess current VMS rules and policies to ensure they work across multiple freeway networks and to modify as necessary • Develop new rules and messaging for major traffic diversion using traveller information around major blockages in the network
Vehicle detectors	<ul style="list-style-type: none"> • Collection of better quality classification data to improve occupancy/capacity estimations • Reduction in number of faulty detectors to improve accuracy of HERO LIVE estimations • Continuing enhancements to improve the quality of data fed into the algorithm • Automated identification of problematic detector data • Fusion of data sources from motorway and surface road detectors, as well as probe vehicle data, to improve data quality
CCTV	<ul style="list-style-type: none"> • CCTV to provide more advanced information on slow moving or stationary vehicles including providing alarms to operators when such events are detected (e.g. a basic automatic incident detection system) • Automated selection of CCTV images in the TMC to focus on deteriorating traffic conditions (e.g. observe slow moving traffic locations detected by SVO data)
LUMS, including VSL	<ul style="list-style-type: none"> • Strategy Manger triggers pre-defined response plans e.g. if a Traffic Control Plan for a tunnel is activated which requires complimentary LUMS response on other sections of road • Assess current LUMS operating policies and rules to ensure they work across multiple motorway networks and modify as necessary e.g. a motorway to motorway interchange • Dynamic LUMS that improve on the operational benefits through increased throughput and safety & awareness due to their adaptive nature. The first step is to develop DVSL to operate with LUMS. The second step would be pre-empting lane and carriageway closures with alarms to the operators • Additional LUMS policies and rules using additional lane symbols to address more complex network configurations (such as at a motorway to motorway interchange) • Additions to standard message libraries of more complex VMS displays that are combinations of diagrams and lane control symbols to advise motorists of incident conditions ahead and the available lanes and route choices

