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Managed Motorway Design Guide

Volume 2: Design Practice

Part 3: Motorway Planning and Design



Part 3: Motorway Planning and Design

Managed Motorway Design Guide

Volume 2: Design Practice

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Volume 1 - Managed Motorways - Role, Traffic Theory and Science

- Part 1 - Introduction to Managing Urban Motorways
- Part 2 - Traffic Theory Relating to Urban Motorways
- Part 3 - Motorway Capacity Guide
- Part 4 - Road Safety on Urban Motorways
- Part 5 - Linking Investment and Benefits Approach



Volume 2 - Managed Motorways Design Practice

- Part 1 - Managed Motorway - Design Principles and Warrants
- Part 2 - Managed Motorway - Network Optimisation Tools
- **Part 3 - Motorway Planning and Design**
- Part 4 - *LUMS, VSL, Traveler Information (Update Under Development)*

Part 3: Motorway Planning and Design

Volume 2: Design Practice

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Notations and Abbreviations

ALINEA	Asservissement Linéaire d' Entrée Autoroutière, -i.e. Linear feedback control of a motorway on-ramp
ABC	Advanced bottleneck control
C_r	Cycle time of ramp signals (seconds)
c_a	Cycle time of the surface road / entry ramp intersection signals supplying the arriving vehicle platoon to an entry ramp (seconds)
CCTV	Closed circuit television
CD	Collector distributor
FRS	Freeway ramp signals
HERO	HEuristic Ramp metering co-Ordination
HGV	Heavy goods vehicle
HOV	High occupancy vehicle
JUMA	Joint use mast arm
JUP	Joint use pole
LED	Light emitting diode
LUMS	Lane Use Management System
O_{cr}	Critical occupancy
MSFR	Maximum sustainable flow rate
pc	Passenger cars
PCE	Passenger car equivalents
PFN	Principal Freight Network
PHF	Peak hour factor
q_{us}	Freeway mainline flow upstream of entry ramp (veh/h)
q_{cap}	Freeway mainline capacity at critical bottleneck (veh/h)
q_{ra}	Ramp arrival (demand) flow (veh/h)
q_{rca}	Ramp arrival (demand) flow in vehicle platoon during cycle time c_a (veh/h)
q_{rn}	Metered entry ramp flow from a number of ramps (veh/h)
n_{r95}	Number of ramp vehicles in a 95th percentile queue (No.)
$n_{rMax-wait}$	Number of ramp vehicles in a queue based on the maximum wait time (No.)
n_{rMean}	Mean number of ramp vehicles arriving in cycle time c_a (No.)
L_{rDes}	Length of desirable ramp storage (metres)
L_{rm}	Length of mean ramp storage (metres)
L_{vs}	Average length of a vehicle storage space in a ramp queue (metres)
RRPM	Retro Reflective Pavement Markers
SCATS	Sydney Coordinated Adaptive Traffic System
$t_{Max-wait}$	Maximum wait time for vehicles in a ramp queue (minutes)
v_f	Mean free speed
VHT	Vehicle Hours Travelled
VKT	Vehicle Kilometres Travelled
VMS	Variable Message Sign
VSL	Variable Speed Limit
TMC	Traffic Management Centre

A Glossary of Terms and Traffic Flow Relationships is provided in Appendix C.

Volume 2: Design Practice
Part 3: Motorway Planning and Design

Chapter 1: General Introduction



1 General Introduction

1.1 Context

This part of the Motorway Design Guide focusses on motorway planning and design for safe and effective system operations.

Volume 2, Part 1 of the Guide sets out the design principles and process as well as warrants for the provision of managed motorway tools and associated infrastructure. The warrants and requirements outlined in Part 1 need to be considered alongside the more detailed guidance in this part covering recommended and prescribed geometric layouts, control tools, systems and device requirements.

Volume 2, Part 2 describes the operational aspects associated with optimisation tools utilised on managed motorways. Part 2 provides the operational principles and common aspects that inform both geometric provisions, system and device requirements outlined in this part. There is an extensive focus on the utilisation of City Wide Coordinated Ramp Metering (CWCRM), being the primary optimisation control tool currently utilised by VicRoads. Future expansion of Part 2 is expected with ongoing development of complementary optimisation tools such as Dynamic Variable Speed Limits (DVSL).

Volume 1 of the Motorway Design Guide focuses on the role of motorways as well as theory and traffic science. The principles for motorway analysis and design in this part embrace, and build on, the traffic theory and operational principles in Volume 1 of the Guide. The design methodologies are therefore a practical application of contemporary traffic science aimed at maximising resilience and operational flexibility, as well as the potential to achieve and contribute to optimum urban network performance.

Chapter 3 of this part focusses on the planning and choice of concept designs for mainline carriageways and ramps that need to be considered using motorway design principles that will contribute towards optimising operation of the network. Further more detailed concepts and principles are in Chapter 4.

A formal review of designs and analyses by a reviewer(s) with appropriate expertise and independent of the project is desirable at concept and detailed stages of the project development to ensure operational and safety aspects have been addressed. The Main Roads Western Australia 'Operational Efficiency Audit Guidelines for Managed Freeways' (2013) provides useful guidance for this purpose.

Further guidance relating to the complexity of traffic flow problems and operations, business case development and economic analysis are provided in Volume 1, Parts 2 and 5.

Guidance related to other traffic management systems such as a lane use management system (LUMS), traveller information and variable speed limits (VSL) is provided in VicRoads Managed Freeways Handbook for Lane Use Management, Variable Speed Limits and Traveller Information (VicRoads, 2013).

1.2 Background

The era where road reservations for motorways were planned and set aside many years earlier for the purpose of building future motorways, or where motorways were progressively built and upgraded to meet traffic demand as the city expanded as populations grew, is receding in many large urban areas. During this era, it was possible to design new and upgraded motorways by targeting forecast demand for the design life (not just at opening), and then applying applicable road and traffic design standards.

In the current era, projects are generally no longer just a civil design exercise. They require considerably more understanding of current problems and operation in the context of the broader road

network, as well as anticipated future operation and performance. The current network environment may also have limited opportunities for widening of motorways or establishment of reservations to meet current demands, let alone forecast demands. Many corridors have reached their practical limits, especially during extended peak periods, and there may be a need to focus on targeted civil upgrade improvements (based on traffic analysis) and retrofitting with traffic management devices to improve safety and/or capacity and provide the ability to manage actual demand.

A further aspect of the current era is that it may not be possible to meet the traffic demands for a desirable design life for major projects where widening is feasible, or where new links can be provided in the network but are limited in the additional capacity that can be delivered due to high cost or other constraints (for example, most tunnel options). This outcome then requires special consideration of optimising design aspects and operational strategies to ensure they can be managed to Maximum Sustainable Flow Rates (MSFR) in real time.

1.3 VicRoads Approach to Planning, Design and Operations

The VicRoads holistic approach to managed motorways focusses on design for safe and efficient system operations. The 'designing for operations' approach incorporates various aspects of planning, analysis and design as part of a comprehensive performance-based design methodology.

Optimisation of road networks requires a shift from individual project led decision making around design, implementation of isolated network improvements and adding ITS devices to an existing motorway, to adoption of a holistic approach which considers performance-based design for best overall route and network performance to inform project level decision making.

The principles in this part of the Guide can be applied to:

- **Existing motorway improvements** – to retrofit a new coordinated ramp metering system to improve safety and productivity from existing infrastructure. Other localised works would generally be needed, including vehicle detection and physical modifications at entry ramps or other motorway improvements.
- **Existing motorway upgrades** – where additional capacity (widening or reconfiguration to treat operational capacity constraints) and improved interchanges are being provided to improve capacity and travel time reliability.
- **New motorway design** – for a new major link in the arterial road network.

1.4 Performance-Based Design

In this current design and operational environment, more sophisticated and robust approaches are needed for decision making during project planning, analysis, design and operations. Ongoing operational strategies into the future to manage demand and optimise performance also become essential for best sustainable network outcomes, as well as timely maintenance interventions for operation of systems and devices.

In this context, performance-based design becomes a specific focus where new or upgraded infrastructure needs to bring together many elements of managed motorway operations into the design, with a focus on design and operation intent (such as safety and productivity performance outcomes), as well as an understanding of operations and maintenance elements.

New approaches require collection of traffic data, data analysis and refinement of traffic modelling which, while they may sound traditional, need to be combined with the adoption of new or appropriate design thinking. This thinking links physical features to likely operation performance such as traffic turbulence, bottleneck triggers and capacity impacts. It also requires an understanding of the managed motorway toolkit, including the relative benefits of the various traffic management systems that can guide designers and project managers in priorities. Motorway design is no longer just a

geometric design and alignment exercise – it considers the impacts of multiple dynamic elements impacting driver responses and interactions in the context of the design.

Designers need to be fully aware that there are now many integrated managed motorway real-time backend systems and automated decision support services requiring the provision of accurate data from the field for real-time feedback control, historical analysis and performance measurement. The road designer and/or project delivery manager must be cognisant of the downstream operational activities that will occur in the future. These matters place particular attention on the design decision making processes and the technology provided, e.g. the precise location of vehicle detectors for richer data sets requiring high accuracy and high levels of availability.

The performance-based design approach also focusses on project specific conditions as well as existing and future roadway performance, rather than just meeting nominal geometric design standards.

Further background on performance-based design is provided in Volume 1, Part 5.

1.5 Design Intent

The design intent shall be established in the early stage of project development.

As a general principle all motorway projects should be focussed on delivery of optimum safety and productivity outcomes with attention to provision of ITS traffic management tools in accordance with the warrants and criteria in Volume 2 Part 1 of the guide, as well as physical design for optimum operation in accordance with Part 3, and other parts of Volume 2.

The attention to performance outcomes (refer Section 1.4) will provide the necessary focus within the planning and design processes for functional design concepts, choice / priorities of traffic management tools (based on benefits), and guidance in decision making when considering options and implications.

Note:

An analogy can be drawn to the design of different types of motor vehicles. Establishing the initial design intent when designing a vehicle is essential before the design commences. If the vehicle is to be a high performance motor car, then the performance outcomes are foundational to the car design, e.g. engine power, mass, steering, braking, etc. But if the performance outcomes relate more to a conventional family vehicle or an off-road vehicle, then a different design intent (with corresponding design features) is necessary prior to commencing design.

Similarly, for a specialised vehicle the standard, frequency and cost of necessary maintenance, servicing parts and tuning can be expected to significantly influence the performance outcomes, i.e. the costs and frequency of servicing a highly utilised vehicle with high-tech motor, control system, tyres, suspension, etc. are expected to be higher when compared to a less utilised conventional family vehicle.

Similarly, different parts of the road network, and indeed different parts of urban motorway networks need to be designed for their intended operational context and take into account features that may be unique to the localised conditions of the motorway corridor and surrounding road network. Static factors, such as geometric constraints and network configurations, may be straightforward to identify. Dynamic factors (such as demand flows that regularly change and sometimes exceed capacity), over short, medium and long time frames can be more difficult to gauge and incorporate in design.

A standardised cross section and access arrangement may be appropriate when flows are generally less than capacity, however, more complex design layouts and control applications may be required when demands regularly exceed capacity for significant periods each day.

1.6 Project Planning and Interaction

In the context of motorway development, the ‘owner / purchaser’ (road agency) and the project manager / designers need to make consistent design decisions based on performance outcomes if objectives are to be achieved, as well as on budget for not only initial provision of infrastructure, but also for ongoing operations, performance management and maintenance.

In establishing the desired performance outcomes and design intent, various factors come into play, including the project scope and budgets. ‘Painting the picture’ in relation to project objectives and how these will be achieved, as well as providing realistic expectations of project outcomes, is also important. A number of high-level, inter-related factors are shown in Figure 1-1.

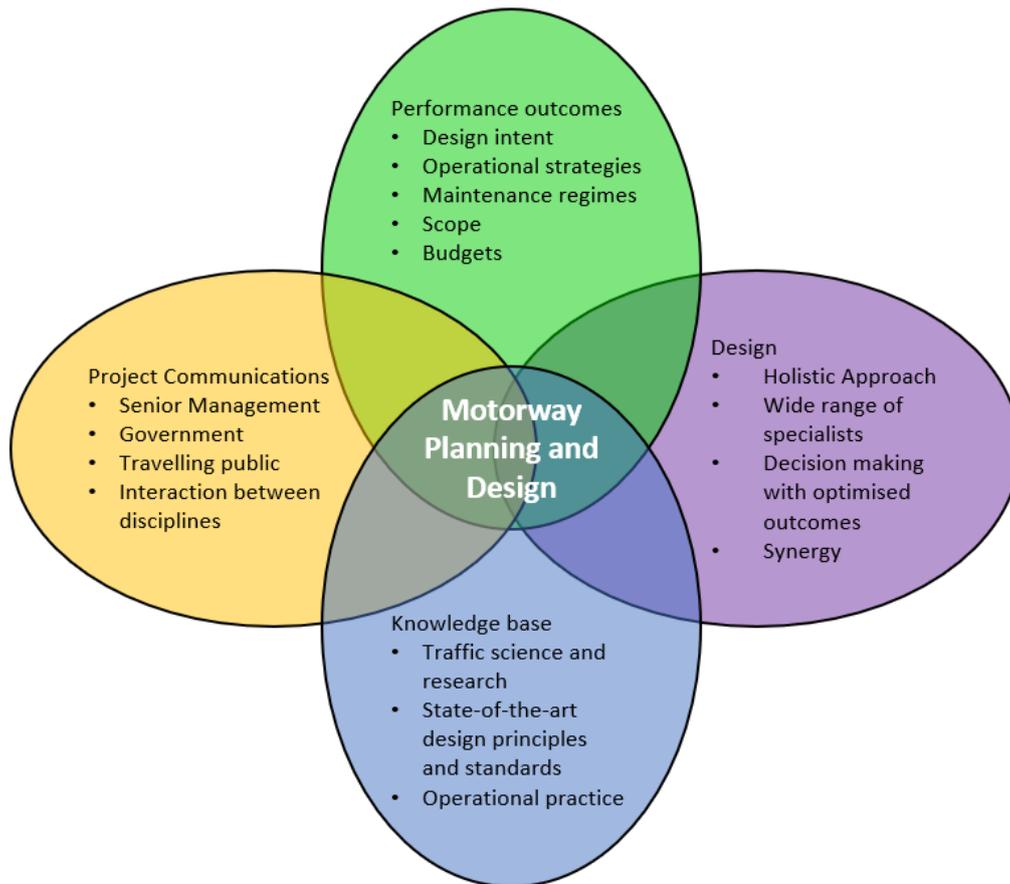


Figure 1-1: Motorway Project Development Interactions

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Chapter 2: Motorway Planning



2 Motorway Planning

2.1 General Principles

Managed Motorway planning and concept design aims to provide infrastructure with appropriate capacity and functionality to best accommodate traffic demand, where the mainline, entry ramps, exit ramps and interchanges provide adequate capacity to enable demands to be managed considering whole of network impacts, and to identify traffic management and control tools needed for operations. An overview of the Managed Motorway planning and concept design process is in Figure 2-1. This process should be undertaken at network and corridor level and possibly broken down to project level requirements.

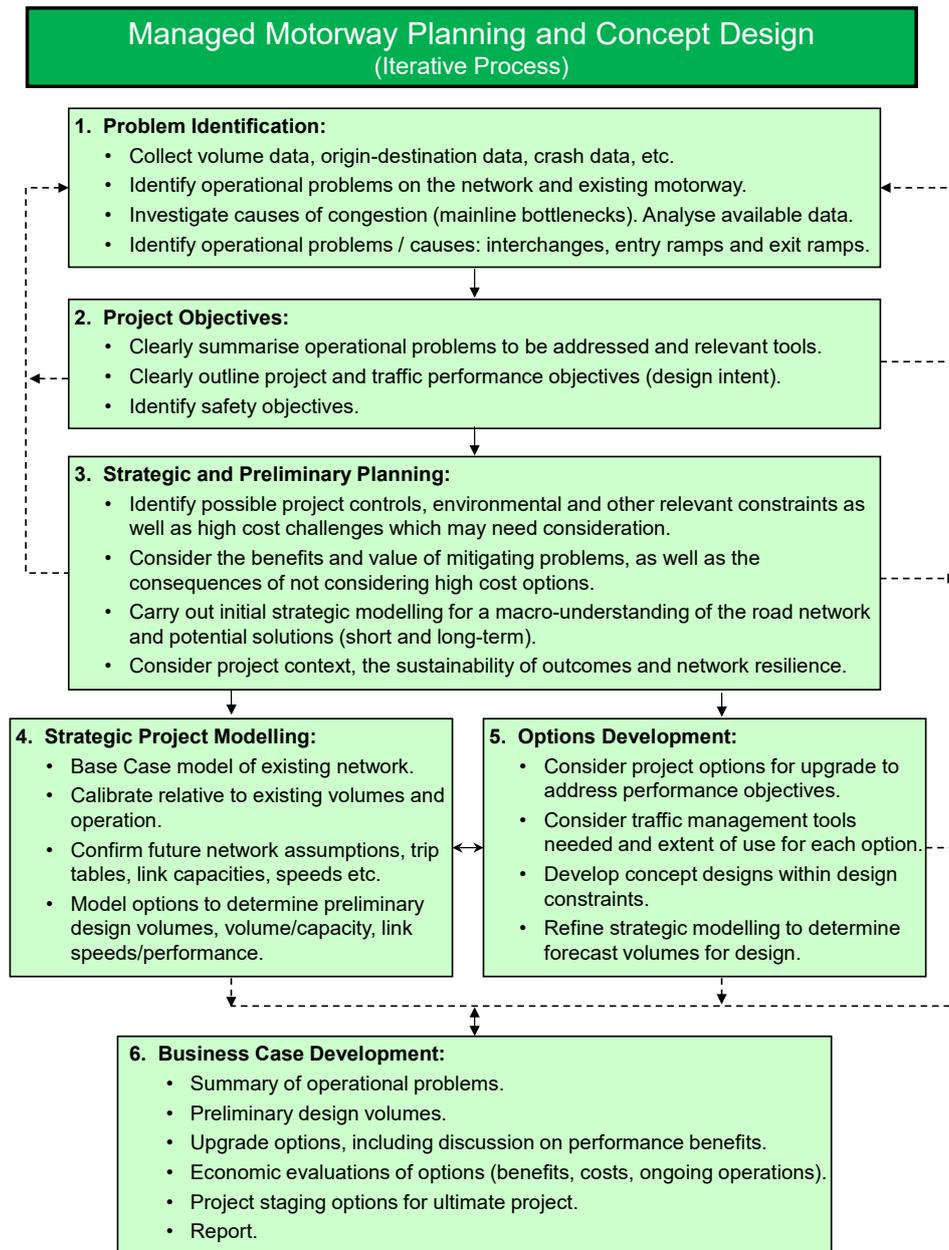


Figure 2-1: Overview of Managed Motorway Planning and Concept Design

Planning and concept design general includes understanding the nature of motorway problems, determination of traffic demand, analysing design volumes relative to capacity, consideration of feasible options for improvement, project scope, quantifying benefits and costs, staging of works and business case development.

As project budgets and funding are generally determined during this stage of project development, adequate and appropriate consideration of concept detail is necessary, so that there is sufficient understanding of project implications and constraints during the next phase of project development where more detailed analysis and functional design is carried out (refer Chapter 4).

In parallel with this general process for traffic and road investigations, other related investigations may also be needed involving various stakeholders and other disciplines, e.g. noise, structural, drainage, indigenous heritage, etc. as well as investment logic mapping or other government project requirements which may change from time to time.

Managed motorways planning and concept design requires a system approach with consideration of network and route performance. Concept development for a motorway route or upgrading requires investigation along a significant length of motorway to gain an overall understanding of motorway performance, infrastructure characteristics and existing / potential bottleneck locations affecting the design and scope of a motorway upgrade project. All these factors are important to ensure traffic operations and safety are the main drivers in decision making, rather than purely economic or other considerations.

2.2 Iterative Design Process

The Managed Motorway planning and concept design process shown in Figure 2-1 indicates that an iterative process is generally required. This is consistent with good practice for design development of most projects, and for major motorway upgrades may take years. Exploration of options is necessary as feasibility or decisions relating to one component can have significant implications for other components of analysis and design, as well as scope of works and costs.

The process establishes preliminary peak period design traffic volumes for consideration of initial options and preliminary cost estimates leading to Business Case development. These are then refined further, together with more detailed volume / capacity analysis as part of developing the functional design (refer Chapter 4).

The planning process also needs to consider the traffic management devices for control and operations after construction. This should include development of a traveller information strategy and consideration of incident management. As part of this concept design there should also be a focus on cost savings and grouping of ITS assets near each other to facilitate constructability and maintenance.

For motorway upgrade projects, a general principle is that the ultimate motorway needs should be determined first (refer Section 3.3.2). After the ultimate project concepts and analyses are finalised, any initial and subsequent staging options are considered to ensure that satisfactory Managed Motorway operation and outcomes can be delivered and sustained in the short term and long term (refer Section 3.3.2) and that future development of the asset is not unnecessarily limited. This can also reduce the extent of reconstruction, disruption and cost when other future upgrades are carried out.

2.3 Other Project Planning Considerations

Reference also needs to be made to the Austroads Guide to Traffic Management, Austroads Guide to Road Design and the VicRoads Supplements to the Austroads guides.

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Chapter 3: Motorway Concept Design



3 Motorway Concept Design

3.1 Preliminary Design Volumes (Mainline and Ramps)

The analysis of existing data and/or strategic traffic modelling to determine preliminary motorway design flows is an essential first step in the overall concept design process.

Realistic and appropriate design volumes are essential to ensure appropriate motorway design of the mainline lane configurations relative to design capacity, as well as design of entry ramps, exit ramps and interchanges.

Guidance relating to establishing design volumes and identifying other matters relevant to the design for retrofitting existing freeways / motorways is provided in Section 3.2. Guidance relating to motorway capacity upgrade projects or a new motorway is in Section 3.3.

3.2 Enhancing Existing Motorways (Including Retrofit of Ramp Metering Signals)

3.2.1 Investigations

Investigation for the upgrading of an existing route should include collection of data (using existing detectors or arranged traffic surveys), data analyses and on-site observations for consideration of:

- Mainline volumes for all motorway segments (with detector data validated). Where detector data is not available, traffic surveys over a significant period (say 2 to 4 weeks during non-holiday periods) will generally be necessary.
- Likely magnitude of suppressed demand based on historical records.
- Entry and exit flows at all ramps from detector data or traffic surveys.
- Identification of critical bottlenecks due to merging traffic or other bottleneck locations such as geometric features, e.g. at lane drops, steep upgrades, tight curves, width restrictions or sight-line restrictions.
- Segments with significant lane changing (including weaving between interchanges, particularly closely spaced entry-exit ramps with high flows).
- By observation and data analysis, exit ramps where queues extend back into the through carriageway. This problem cannot be treated with ramp metering and requires consideration of other improvements to alleviate the problem.
- From analysis, the locations of new critical bottlenecks that are likely to emerge after the ramp metering installation due to increased flows from resolved bottlenecks, e.g. increased throughput at a bottleneck being alleviated by ramp metering may trigger a new critical bottleneck further downstream.
- From analysis, interchanges that are likely to need upgrading due to increased flows on the motorway, e.g. increased capacity or improved throughput at a bottleneck being alleviated by mainline management will result in increased flows at the interchange (for both entry and exit).
- Extent of project limits and scope to ensure managed motorway outcomes are achieved (also refer Section 3.3.3).
- An Origin-Destination (O-D) study should be carried out as it provides an understanding of existing trip patterns for traffic movements. This is critical for understanding weaving and lane changing areas that could cause turbulence and impact capacity (refer Section 4.3.2.9). It also helps evaluate how robust strategic model ramp volume outputs are relative to current travel patterns. O-D information from strategic models, e.g. select link assignments, may need to be

used as an interim approximation but generally cannot replace O-D traffic surveys as a basis for considering detailed design, or for evaluation of ramp volumes from a strategic model either during the calibration or forecast phases of the modelling.

- Safety or crash investigations should be considered as a complementary investigation as part of the problem identification and project development process.

Based on the high-cost nature of motorway projects, investment in the investigation phase of project development is essential. This enables more accurate identification of existing problems and improved knowledge and background for subsequent development of project options and interpretation of strategic modelling. The above information should be collated prior to the problem identification process.

3.2.2 Design Traffic Volumes

The design traffic volumes for upgrading an existing route need to be based on investigations that consider a number of factors:

- **Existing traffic volumes.** These are needed during the 6 to 9 AM and 3 to 6 PM peaks with measurement on the mainline upstream of critical bottlenecks and over a sufficient period (say a month), during non-holiday periods, and also considering Friday PM and Monday AM volumes if impacted by weekend trips. This is to ensure an understanding of current mainline traffic flows in both directions of travel as well as at entry ramps, exit ramps and interchanges. At some locations consideration will also need to be given to shoulder / inter-peak periods as there can be different (higher) ramp demands and patterns, i.e. high ramp flows may not coincide with the mainline peak flows but still need to be considered for ramp discharge and storage.
If annual traffic information is available, a proportion of the AADT (30th highest hourly volume) may be appropriate for use as outlined in Austroads Guide to Traffic Management Part 3 and refer to Volume 1, Part 3: Section 2.9 of this Guide.
- **Analysis of existing operation.** Analysis of existing routes during the peak periods that considers measured flow, speed and occupancy data. Analysis seeks to understand the current traffic demands, and the bottleneck problem areas where recurrent congestion is occurring on a regular / semi-regular basis and the associated mechanisms of flow breakdown. This analysis can ensure that solutions address current traffic problems.
- **Ramp Demands:** When considering existing ramp detector / survey data for design, the highest 5 minute flow (factored up to an hourly flow) should be the basis for considering minimum ramp demand for discharge and storage, rather than an hourly flow which may not reflect varying ramp demands during the peak period. If 5-minute flows are not available the maximum 15 minute flow may be used and factored up by 5%.
- **Mainline:** When considering existing mainline data as a basis for determining design volumes, the highest mainline 15 minute volumes along the route (prior to any flow breakdown), and especially at the highest flow locations (also considering the motorway in-flows and out-flows at the start and end of project), is factored up to an hourly flow. Exit and entry ramp volumes consistent with these highest mainline flows (the same 15-minute time period) are considered in the mainline analyses. 15-minute flows are used rather than hourly flows (which often reflects congested flows), as this leads to more realistic design volumes and also better alignment with the 15-minute period used in the process for determining the maximum sustainable flow rates for mainline analysis.
 - For determining hourly design volumes for a route where the number of lanes is not being increased, consideration needs to be given to using existing volumes as outlined above, with consideration of traffic growth and/or accounting for potential suppressed demand.
- **Traffic growth.** Traditionally, traffic growth has been based on an analysis of historic traffic surveys over previous years with extrapolation of the growth trend to a future year.

Alternatively, estimation of forecast traffic volumes at the design year may use existing volumes with an appropriate percentage increase. However, if growth rates have flattened out due to inadequate roadway capacity these types of analyses would generally lead to inappropriate assumptions of future traffic demand.

- **Suppressed Demand (including latent or induced, diverted and unmet or queuing demand).** Where existing capacity has restricted motorway traffic growth, the existing hourly flows may not be representative of actual peak traffic demand, e.g. due to peak spreading. Therefore, adjustment of demand may be needed, subject to the scope of the motorway upgrading being considered. Suppressed demand would generally exist if growth rates have flattened, if inadequate mainline capacity causes recurrent congestion, or where it is known that road users are avoiding the motorway and taking alternative routes.

Suppressed demand should be factored into projected design volumes where the practical capacity constrains actual growth along a motorway.

- **Demand from Strategic Models** (also refer Section 3.3.4). In some situations an indication of traffic demand may need to be determined by using strategic traffic modelling as part of the iterative design and analysis process. Where the project development process indicates that the design is not able to meet demand, this needs to be clearly documented as part of the analysis process – refer Section 4.4.7.

It should be noted that the demand indicated by strategic models may be distorted by the capacity available in an upgrade option being modelled, e.g. capacity constraints within a model may divert traffic away from the motorway which may not be reflective of the demand that desires to use the motorway. To identify and appreciate the true nature of the traffic demand and distribution, sensitivity modelling of an option with higher, but reasonable level of additional capacity is advisable (i.e. an unconstrained model – refer Section 3.3.4.2).

- **Proportion of trucks.** The traffic mix on the mainline during the peaks may be different to the daily proportion. This should be determined as it is factored into design capacity values (maximum sustainable flow rates) for analysis, and may also be important on specific ramps if a priority access lane is being considered.
- **Bus routes.** This may need to feed into design for priority vehicles on relevant entry and exit ramps. Information relating to special use mainline facilities is provided in Section 4.3.2.11.

3.3 Upgrading Motorway Capacity or New Motorway Projects

3.3.1 General Approach

For an existing motorway capacity upgrade project (with widening), the investigation should start with consideration of matters outlined in Section 3.2. This will provide background and information needed for consideration of upgrade options. In general terms, the deployment of ITS should not replace, nor remove the need for, consideration of other civil upgrades to address safety or other traffic operational problems (refer Volume 1, Part 1: Section 2.4.2).

For a capacity upgrade project that includes widening, or when providing a new motorway link in the network, macroscopic and/or mesoscopic traffic assignment models are used for the estimation of future year forecast traffic design volumes as well as outputs for economic project appraisal. Further guidance relating to modelling is in Section 3.3.4 as well as in Volume 1, Part 5: Section 5.4. Guidance relating to more detailed analysis and design is in Sections 4.3 and 4.4.

3.3.2 Staging Strategy for an Ultimate Motorway Design

Project designs should generally start with consideration of ultimate long-term motorway requirements. This will then provide a context for considering options, or for staging of works to suit budgeting profiles or a shorter timeframe for initial upgrading. This approach can minimise rework at a later date, provide assets in ultimate locations, minimise future road user disruption and provide

improved overall cost outcomes. Where future-proofing is being considered, it should allow for a desirable standard of future works where this is feasible, e.g. providing width for a future lane should not just assume trafficking of a shoulder which may mean lower future posted speed for operation.

If the ultimate scope of project works is not implemented as a complete project, the staging of a part of the overall project should also be satisfactory from a traffic perspective to ensure adequate capacity and that bottlenecks can be managed, i.e. to maximise the potential for success, interim stages of an ultimate project should be capable of adequately managing the mainline traffic to prevent and minimise flow breakdown.

Analyses of interim stages should be based on an appropriate project life, i.e. until other project stages or further upgrading are implemented. This may mean assessment based on existing flows (adjusted for growth and/or suppressed demand – refer Section 3.2), or strategic modelling and traffic forecasts for a design year less than that being used for the ultimate project design.

Where ultimate needs are not provided in an initial project staging, e.g. ultimate number of main carriageway lanes are not constructed, ideally the interchanges should still be built to their ultimate standard as these are generally costly to upgrade.

3.3.3 Limits of Control within Project Scope

When considering the extent of the project limits and scope for control of demand, the achievement of managed motorway outcomes also needs to consider the length over which the controlled ramps are provided within an overall project scope. In some cases, the extent of ramp metering may need to extend upstream beyond the formal limit of a motorway upgrade project.

Fully managed mainline capacity with coordinated ramp signals is significantly greater than unmanaged capacity. This managed capacity does not increase instantly after the first metered ramp but takes some distance for the coordinated benefit of several ramp meters to provide the managed motorway benefit. This area near the start of a managed system is considered a Partially Managed Transition Zone (PMTZ) – also refer Section 4.4.5.

The PMTZ shall be given consideration at both the concept design and detailed design stages of project development. Further information relating to a concept level assessment is provided in Section 4.4.5.2. Further detailed incremental capacity analysis is provided in Section 4.4.5.3.

3.3.4 Strategic Traffic Models

This section does not provide details of how to carry out traffic modelling, but is focussed on providing background, awareness and guidance relating to the modelling process and the use of traffic forecast outputs for motorway analysis and design. Further information about modelling is in Volume 1, Part 5: Section 5.4, and VicRoads Draft Transport Modelling Guidelines Volumes 1, 2 and 3 (2012).

Strategic traffic models are based on projected travel demands where assumptions are based on population and employment patterns, future land use, mode choice and travel behaviour. The traffic estimates will change with the assumed characteristics of the transport infrastructure and changes to other underlying assumptions. An iterative modelling approach is required with feedback and refinements relating to model assumptions as well as the project design, including the scope and lane configurations etc., as these can directly influence modelled flow forecasts. The models may also be applied to various project scenarios or options being investigated.

The English statistician George E. P. Box (1919 - 2013) famously said, “*All models are wrong but some are useful.*” He also said, “*.... the practical question is how wrong do they have to be, to not be useful.*” Therefore, considerable expertise and oversight is needed in developing and accurately coding traffic models in both the calibration phase (base case to replicate existing network operation) and for the assessment of project options. Similarly, design and traffic engineering experience and judgement is required when managing strategic modelling, as well as in using the strategic model outputs. A sound knowledge of actual motorway and road network operations, including consideration

of flow breakdown and congestion flows (from investigations), will assist the traffic and road designers through this process.

The strategic traffic volume implications resulting from a new motorway or major upgrading project generally extend well beyond the immediate vicinity of the works. Therefore, the extent of the study areas covered by the model needs to include existing alternative strategic routes (including other motorways and major arterial roads) to identify the potential changes to travel patterns.

Base year model calibration is the initial step in the modelling and aims to replicate the existing road network and traffic. During this process there needs to be specific focus on calibrating the broader urban motorway network, as well as rigour in the sub-area project network. Future year models are then developed based on future traffic demands and network upgrade scenarios, usually with increasing scope inclusions to provide a scope ladder with associated costs and benefits. Comparing the outcomes of model options for increasing scope ladder inclusions will clearly demonstrate the benefits that achieving managed motorway outcomes bring to projects and broader network benefits.

For all modelling, the motorway capacity values need to be relatively consistent with the Maximum Sustainable Flow Rates in Section 4.3.1 (also refer Volume 1 Part 3) for base case, unmanaged and managed scenarios. Although modelling analyses are not as precise as the volume / capacity analyses described in Section 4.4, every effort should be made to represent speed / flow curves and appropriate Maximum Sustainable Flow Rates for the model runs.

When modelling a Separated Limited Access Carriageway combined with a Conventional Mainline Carriageway (refer Section 3.5.3), both carriageways are generally designed and constructed to normal mainline motorway standard and speed limit, i.e. although the Conventional Mainline Carriageway acts as a Collector-Distributor (CD) road, it is modelled as motorway standard element. However, due to its role as a CD road, the Conventional Mainline Carriageway may need to be modelled with suitably adjusted capacity due to the differing levels of turbulence, especially where interchanges and ramps may be closely spaced.

For upgrading an existing motorway, modelling forecasts can be beneficial in determining real existing traffic demand when suppressed demand is a concern (refer Section 3.2).

3.3.4.1 Calibration of Existing Conditions Model (Base Case)

Base year model calibration aims to replicate the existing road network and traffic volumes (not just at screen-lines) before future year traffic and road network improvement scenarios are introduced. The model needs to utilise measured breakdown flows as upper capacity settings during peak periods to ensure that both motorway operations and surrounding network conditions reflect the reduced throughput normally experienced on a congested network. Adjustments to the model are then used to also adjust future year model scenarios.

The calibration provides a level of confidence that the model forms a satisfactory basis for considering future scenarios in regard to traffic volumes and travel patterns. The characteristics for each road link need to reflect the current network, such as the number of lanes, free-flow speeds and appropriate values for link capacities.

The calibration process should include comparison of existing (measured) and base case modelled volumes and, subject to the nature of the project, may include:

- Volumes on other roads in the network, particularly roads that are generally parallel to the route under investigation.
- For upgrading an existing route, volumes using the existing motorway, including consideration of volumes at each entry and exit ramp.
- For a new link in the network, volumes across a screen line, e.g. across an existing barrier such as a river bridge or rail line, to check total traffic entering/leaving an area.

All links in the network (motorway and surface roads) need coding of appropriate capacities and speed limits, etc. Motorway link capacities at observed bottleneck locations need to reflect the measured breakdown flows and travel speeds as well as extent of congestion during peak periods. Bottleneck locations and upstream sections generally experience a significant flow drop after flow breakdown sets in (hence the need for calibration). Speed flow curves in strategic models allow flow to exceed capacity which is not the case in reality. Base model calibration should reflect measured reduced flows by reducing the link capacities if such areas experience flow breakdown for extended periods during the peak period, i.e. there needs to be care that capacities are not artificially high or artificially low.

Correctly reflecting existing base case flows, i.e. not just considering screen-lines, more clearly demonstrates project benefits. Therefore, road and traffic designers need to have access to link capacities as well as speed and volume plots covering a wide area (i.e. 5 to 10km) around the corridor so that the base and forecast models can be assessed for sensibility. Often a motorway corridor or an arterial road is at capacity in the model in the base case or forecast years and the model will try and route traffic around the problem.

It should be noted by modellers and designers that, when there is extensive queuing under pre-existing traffic conditions, it is likely that the volumes used for calibration of the base conditions could under-represent demand by an unknown amount that could be significant due to the loss of flow when there are breakdown flows. Modellers in the past may have been unaware of this important understanding and inferred that affected links have 'spare capacity'. Breakdown flows occur when a link exceeds capacity, thus it is important that strategic modellers understand this phenomena of under-reporting of traffic demands. When examining model outputs there needs to be a focus on traffic speed as well as volume, as this can indicate when assigned volumes are approaching or exceed capacity, and hence indicate if existing conditions are being replicated.

Where recalibration cannot address differences between existing and forecast volumes, an adjustment process for forecast volumes may be necessary.

3.3.4.2 Forecast Model Outputs (Project Cases)

Strategic traffic models of future operation need to reflect long term development scenarios, anticipated general road network improvements, as well as potential motorway project options.

Strategic traffic models can generally provide the following information for project planning and design purposes:

- Traffic demand for a future year that is not dependent on potential project scope or budget considerations. An 'unconstrained' model can provide an indication of true demand and hence what project improvements may be needed to satisfy the real travel needs. This may require greater extent of capacity improvement relative to what may be a likely project upgrade outcome.
- Traffic volumes of estimated daily or two-hour peak volumes on all links in the modelled road network, including motorway ramps.
- Estimated volume divided by the capacity (volume/capacity plots) for each link in the modelled road network.
- Estimated speed plots for each link in the modelled road network. By examining model output speeds this can indicate when assigned volumes are approaching or exceed capacity.
- Volume difference plots comparing two modelled scenarios.
- Select link plots to indicate the estimated traffic on a nominated road link and the links used by that traffic, i.e. an indication of origin and destination.
- Project benefits for the purpose of economic appraisal (generally estimated from savings in vehicle operating costs, travel time and crashes), by comparing a project case with the base case or a 'do nothing' scenario.

3.3.4.3 Managed Motorway Design Informed By Traffic Model Forecasts

Modelling outputs from a well-calibrated model provide a valuable and necessary input to project concept design, however, model outputs need to be assessed carefully to ensure they reflect a sound and reasonable basis for project decision making and concept design, i.e. a 'sanity' check. Some areas of concern when using modelling outputs are outlined below.

Modelling outputs should be checked to ensure outputs are realistic relative to the existing and proposed network (hence importance of knowledge from investigations and how road networks operate). The speed/flow curves in the model can result in outputs that indicate forecast flows greater than link capacities if demand is high and alternate routes are not available for assignment of traffic. Review is required to check if demand is being met by project proposals or if demand management will be necessary as part of an operational strategy.

Traffic model outputs generally provide forecast volumes for the motorway, entry/exit ramps and interchanges to a reasonable order of magnitude. However, due to the nature of the modelling assumptions and the traffic assignment processes, consideration needs to be given to how much reliance is placed on absolute traffic numbers for individual road links, such as ramps, or for turning movements at an interchange. For example, forecast modelled volumes may be reasonable for trips to/from a general area but may not be reliable for a specific ramp. This can be checked relative to existing volumes for an upgrading project but can be more challenging for a new strategic link in the road network. Furthermore, if a ramp forecast volume seems relatively low (e.g. <500 veh/h), a minimum flow (say 600 to 900 veh/h) could be desirable for design.

It is desirable to understand true traffic demand for a future year by using an 'unconstrained' model to appreciate the likely demands and to provide a guide in determining desirable design layouts. When modelling a project that provides significantly less capacity than the 'true' traffic demand, the model outputs only represent the traffic that can utilise the motorway. Therefore, this can indicate that there will be significant network delays and/or congestion, as the project is not able to satisfy demands. It may also lead to inadequate design for interchanges and ramps, so sensitivity or stress-testing is desirable in this case, potentially with a need to provide an increased level of ramp discharge capacity and/or storage in design.

In utilising modelled outputs, designers may need to adjust or constrain output flows at a particular bottleneck that cannot be improved, e.g. a tunnel, particularly if forecast flows are greater than the link capacity due to the traffic assignment process. This may mean determining design volumes by reducing modelled volumes to reflect the constraints of the mainline links, and then redistributing and balancing entry and exit demand for the project as a whole. Ideally the patterns inherent in the modelled outputs and surveyed data should be carried over to ultimate design volumes for the project, with appropriate compensation for designs at locations where there may be greater demand. A customised link node diagram of the network is a simple tool to assist in design volume development. However, care needs to be taken to ensure volumes are not overly constrained, resulting in under-design during peak periods at the location of concern. Appropriate documentation of this process, the true demand and the implications, shall be reported.

For model outputs relating to an existing motorway, the traffic forecasts should be compared with existing ramp flows and may need to be adjusted according to current traffic travel patterns i.e. generally design volumes for an upgrading proposal should be greater than existing flows.

For modelling forecasts relating to an existing or new motorway project, the ramp volumes may need to be considered indicative, with suitable flexibility, i.e. increased volume, being built into the ramp designs during analyses, or by applying a sensitivity test to assess design implications of varying design volumes. As part of the risk management process given the uncertainty of modelling outputs, the project design could also be 'stress tested' by applying a nominal increase to ramp volumes, e.g. plus 10%.

Design volumes derived from either forecast project modelling options or manual adjustment of volumes, may need to be refined through an iterative process until reasonable and defensible values are determined for analysis and design.

3.3.4.3.1 2-hour peak models

Where 2-hour peak period volumes are provided by the model, a conversion factor of 55% is generally used to determine the peak hour design volumes. Design volumes based on this value will then generally result in more resilient design outcomes for managing the route, even if peak spreading occurs and results in peak periods longer than two hours.

3.3.4.3.2 3-hour peak models

3-hour peak period models and volumes are generally preferred, if available, as usually they better reflect actual demands and travel patterns on heavily trafficked networks. A conversion factor of 37% is generally used to determine the peak hour design volumes.

3.3.4.3.3 24-hour models

In the case of 24-hour models, the Peak / 24 hour factor (K-factor) can vary significantly depending on the nature of the traffic demand and travel patterns associated with various motorway corridors. For example, some radial routes have historically been more tidal in nature in urban Melbourne although this is changing in recent times with shifts in residential density and employment based land uses. The choice of K-factor can have the following implications.

- If the ratio used is too low this can result in infrastructure being under-designed with the facility not meeting traffic demand after construction.
- If the ratio used is too high, the infrastructure could be over-designed with potential for wasting money and resources.

The “rule-of-thumb” K-factor used for urban roads is 10%. Based on analysis of motorway data prior to flow breakdown, the suggested value for urban motorways is 9% (minimum) for design purposes. If a Peak / 24 hour factor is to be determined by considering existing data, the highest 5-minute flow prior to any flow breakdown (factored up to an hourly flow) should be the basis for calculation, rather than a 15-minute or an hourly flow with congestion, as this can lead to a relatively low and inappropriate ratio as shown in Figure 3-1. Several days should be considered in these analyses.

Use of K-factors less than 9% for urban motorway design and planning requires detailed justification and approval by VicRoads.

Where low K-factors are derived from existing data, there needs to be care in the interpretation as this may be due to suppressed demand – refer example in Figure 3-2. This example shows the peak proportion of daily traffic for the Hong Kong Cross Harbour Tunnel. In this heavily utilised crossing, congestion is due to high and suppressed demands throughout most of the day. The proportion of hourly to 24 hour traffic is in the order of 5% for about 15 hours a day

from 4 AM until 11 PM, i.e. 5% is probably the lowest K-factor achievable with continuous high demand throughout the day.

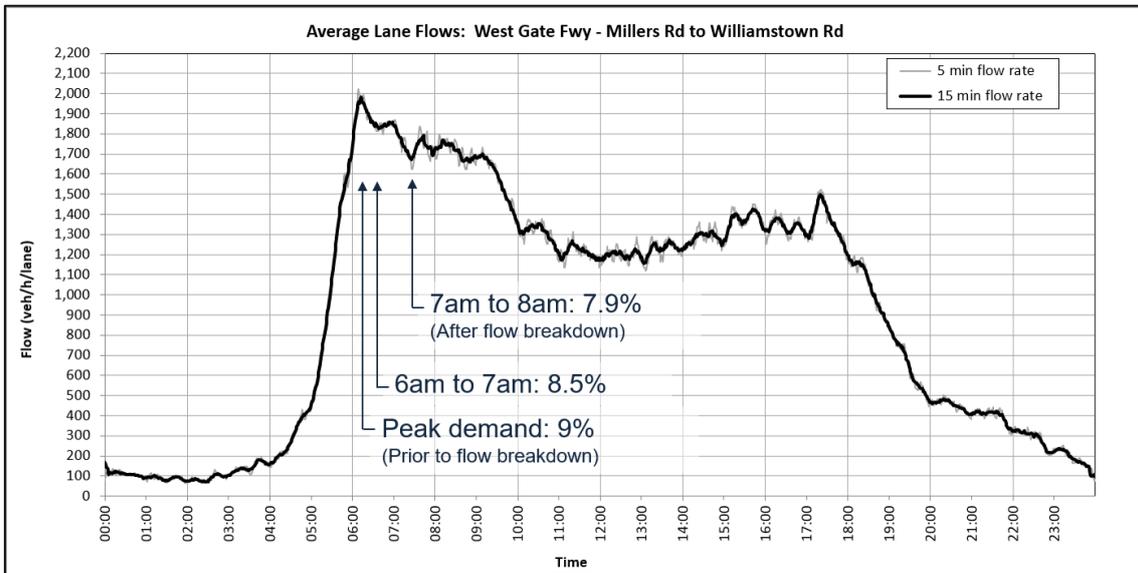
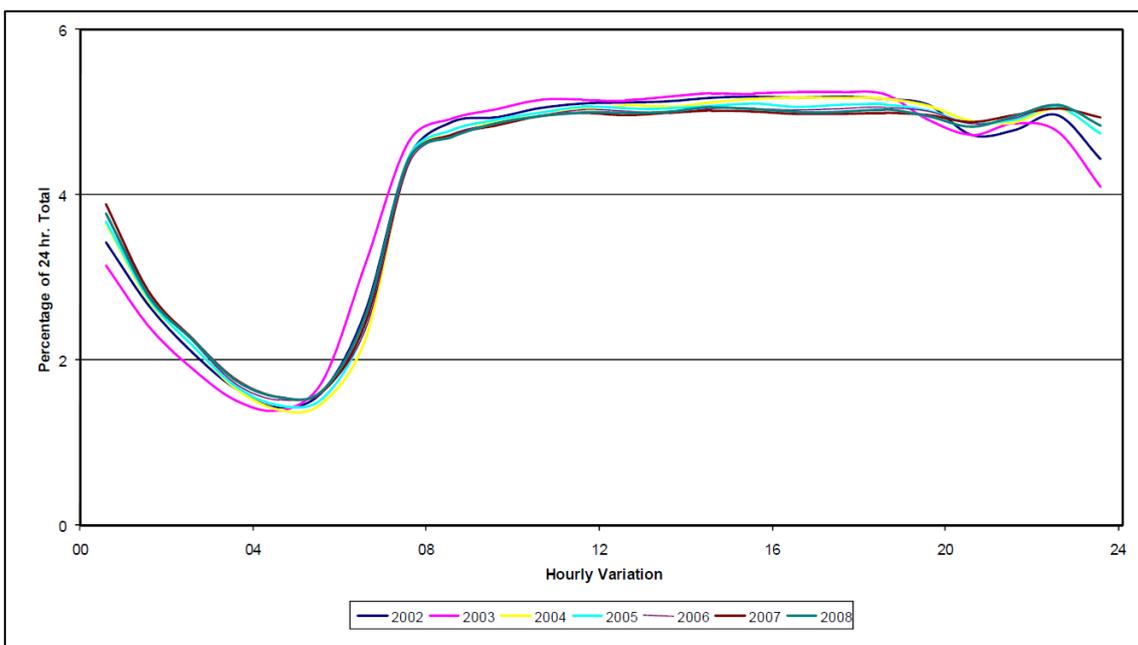


Figure 3-1: Peak / 24 hour factors for various time periods and flow conditions



Source: Hong Kong Transport and Housing Bureau: Consultancy Services for Providing Expert Advice on Rationalising the Utilization of Road Harbour Crossings, Sep 2010.

Figure 3-2: Hong Kong Cross Harbour Tunnel – Peak Proportion of Daily Traffic

3.4 Volume / Capacity Model Outputs

Motorway analysis during the concept design process, including upgrading of existing motorways, relates preliminary design volumes to typical ‘capacity’ values of each link. This can indicate whether forecast volumes are within, or exceed capacity, and where speed outputs from the model indicate inadequate capacity, or if proposals based on previously determined project budgets are able to meet traffic demand (refer Section 4.4.7).

Capacity values used in the strategic model should, as closely as possible, reflect design Maximum Sustainable Flow Rate values associated with road sections and critical bottlenecks that impact

section performance (refer Section 4.3.1 and Volume 1, Part 3: Section 2). While in a strategic model this will be a single capacity value for similar motorway links, i.e. no adjustments for characteristics that impact actual motorway capacity and operation such as grade, heavy vehicles, etc., a single value will provide reasonable indications of capacity for concept design.

During functional design (refer Part 3, Chapter 4), a more detailed analysis process using Maximum Sustainable Flow Rates, adjusted as necessary, is used for analysis and design. This provides a more accurate, higher level of understanding of how the project will perform after construction and ensure that adequate infrastructure is provided for the forecast traffic demands. It also facilitates the prediction of operational problems (critical bottlenecks) and can assist in identifying the most important ramp designs for control.

Nevertheless, for planning and concept design and consideration of potential project options, the strategic modelling process and analyses enables the project development to proceed prior to moving into the more detailed analysis and functional design phases of the process, where a reduced/refined number of options is typically progressed. The strategic modelling analyses also provide economic evaluation to assist in the comparison of options.

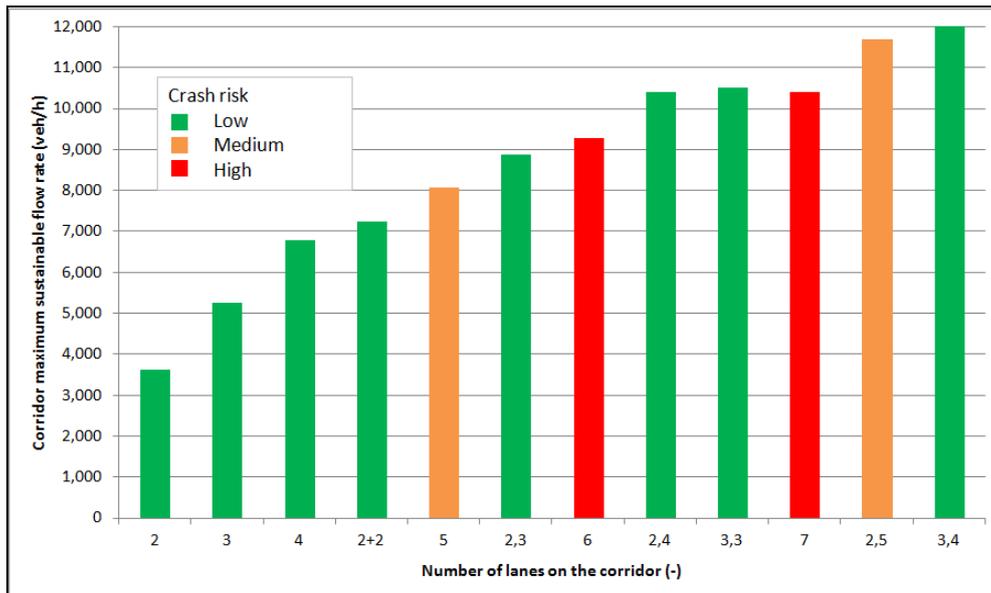
3.5 Mainline Carriageways

3.5.1 Context

The design of mainline carriageways for major through traffic movements typically includes a single mainline with entry and exit ramps. In challenging urban environments and where freeway facilities require upgrading to accommodate heavy traffic demands and complex access arrangements, this has required a shift away from design approaches that have historically catered for conditions where demand does not exceed capacity. The shift to adopting changes to previous practices is intended to ensure dynamic traffic issues are adequately addressed and ensure satisfactory operation after construction under a wide variation of demands across the day.

Good motorway design practice focuses on minimising turbulence and maximising operational safety and capacity, particularly for motorways with either high volumes (i.e. needing wide carriageways), or for complex interchanges where high volume traffic movements need to be accommodated with separate mainline connections.

While increasing carriageway width has been a standard solution for increasing capacity, other solutions to address increasing demand include multiple separated carriageways for increased safety and per-lane capacity along the corridor. Management of access impacts on capacity is also a key part of decision making. Figure 3-3 indicates that ideally 4-lanes should be a maximum number of lanes adopted for through traffic if the aim of the project is to optimise lane and carriageway capacity (auxiliary lanes may also be needed for short distances between interchanges). This figure indicates that as the number of lanes on a carriageway increases, the per-lane capacity reduces and the crash risk increases. While adding physical lanes can provide some level of increased benefit, physical widening in isolation may not always achieve an optimal solution at a local or corridor level. Therefore, when upgrading the capacity of a 3-lane or 4-lane motorway, consideration needs to be given to ultimate corridor traffic demands to ensure that the most appropriate carriageway arrangements are adopted to maximise safety and capacity in both the medium and the long-term, e.g. to avoid a situation where staged widening of a single carriageway results in an ultimate 6-lane carriageway, two separated carriageways may need to be considered to provide superior overall performance. Separated carriageways in the same direction also provide network resilience, particularly for managing traffic during major incidents.



Source: Motorway Design Guide Volume 1, Part 3: Section 2.5 (Figure 2-5)

Figure 3-3: Maximum Sustainable Flow Rates for Separated Carriageway Lane Configurations showing a comparison with safety outcomes for separated carriageway configurations.

As motorway capacity along a corridor reaches a practicable maximum, there may also be a need to invest in other transport corridors to service network demand and to provide network resilience.

3.5.2 Conventional Mainline Carriageway (CMC)

Conventional limited access freeways have traditionally been the basis of limited access freeway and motorway design, and are typically the initial form of construction along a freeway corridor. Access control for entering and exiting traffic is provided at grade separated service interchanges. A sketch of a conventional mainline carriageway layout with service interchanges is in Figure 3-4.

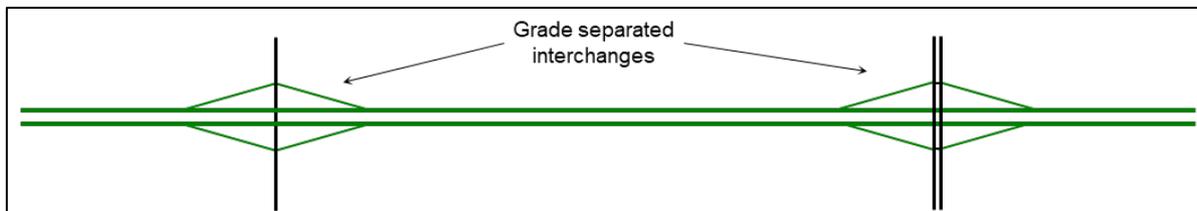


Figure 3-4: Conventional Mainline Carriageways

Weaving manoeuvres generally occur on the main carriageways although auxiliary lanes may be provided to increase localised operational capacity (not overall corridor capacity) and reduce turbulence. For some interchanges, access to/from ramps may be combined as part of a CD road layout that reduces the number of exits / entries on the mainline (refer Section 3.7.5).

3.5.3 Separated Limited Access Carriageway (SLAC)

Separated limited access carriageways are mainline traffic facilities which supplement Conventional Mainline Carriageways (CMC) for traffic travelling in the same direction. In a Managed Motorway context, they are generally designed and operated under similar traffic management and control principles to CMCs, i.e. to minimise turbulence, with all entry ramps controlled, provision of lane use management system (LUMS) to manage incidents and other events, variable speed limits, mainline VMS for traveller information, etc.

A sketch showing typical Separated Limited Access Carriageway and Conventional Mainline Carriageway arrangements is in Figure 3-5.

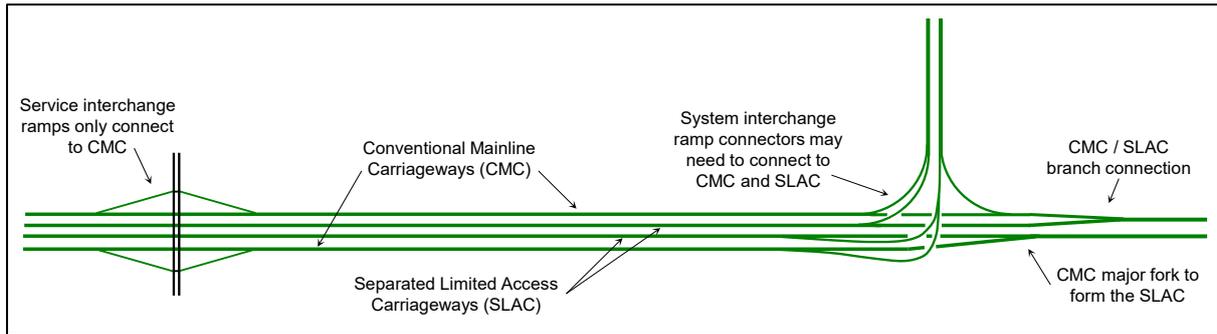


Figure 3-5: Separated Limited Access Carriageway and Conventional Mainline Carriageway

SLACs are generally provided for one, or more, of the following reasons:

- For increased safety and per-lane capacity along that part of the motorway corridor, as well as to limit turbulence associated with lane changing on very wide carriageways.
- To separate high volumes of traffic travelling to different major destinations at a downstream interchange. This arrangement may also satisfy the above objectives to optimise safety, per-lane capacity and to limit turbulence associated with very wide carriageways.
- To provide a separate carriageway for longer distance travel. This arrangement would also limit turbulence associated with entering and exiting traffic as well as optimise safety and per-lane capacity. For this purpose they would generally have a limited number, or possibly no, intermediate interchanges.
- To facilitate the safe and efficient operation in the vicinity of system interchanges.

If separated mainline carriageways are provided along part of a motorway corridor, a CMC is usually part of the overall separated carriageways layout design. In this case, although the CMC may act as a type of CD road, it is designed to a mainline standard, and desirably to operate at a speed limit of 100 km/h unless other design constraints exist. There may also be hybrids of the carriageway types along some routes depending on the length, traffic demands or interchange locations.

SLACs are generally designed according to the following principles:

- Where they are provided for longer distance travel and/or to maximise safety and capacity, they may have fewer points of access compared with a CMC. In this case a separated CMC carriageway will cater for more frequent interchanges and access.
- The 'entry' layout for a CMC into a separated carriageway arrangement would be unmanaged in the form of a major fork bifurcation layout (refer Figure V11.11 in the VicRoads Supplement to the Austroads Guide to Road Design Part 4C – Interchanges (VicRoads, 2010)). With this unmanaged layout, upstream ramp metering would usually be provided to manage demand and traffic flow through the bifurcation. This entry arrangement should have appropriate lane balance that ensures that the number of lanes departing the bifurcation is equal to the upstream number of lanes plus one, i.e. the total capacity downstream of the bifurcation is greater than the upstream capacity.
- The 'exit' arrangement where separated carriageways join to form a CMC would generally be in the form of a branch connection (refer Figure V11.13 in the VicRoads Supplement to the Austroads Guide to Road Design Part 4C – Interchanges (VicRoads, 2010)), and unmanaged due to the high traffic movements. In this case the total number of entering lanes from the two upstream carriageways should be continued downstream to at least the next major exit where the traffic volume on the mainline reduces to a value where a lane reduction can operate satisfactorily. The analysis should also take into account the reduced per-lane capacity applicable to wider carriageways (refer MSFR values in VicRoads Motorway Design Volume Guide, Chapter 2 (2017)).

- Where there is access to/from a system (motorway-to-motorway) interchange, it is usually necessary for connecting ramps to provide access to both of the separated carriageways.
- The physical design arrangements should attempt to limit the ability for similar origin-destination trips to occur in the two separated carriageways.

3.6 Interchange Location and Spacing

3.6.1 Overview

Motorway interchanges at other motorways (system interchanges) and at other surface roadways (service interchanges) enable motorists to enter and leave the motorway (refer Austroads Guide to Road Design Part 4C (Austroads, 2009)), Section 3.1 for definitions of system and service interchanges).

The spacing, locations and layout of interchanges needs careful planning, analysis and design to ensure the interchanges, as well as the motorway segments between interchanges, operate safely and efficiently. Interchange spacing is typically defined as the distance between the centrelines of successive crossroads with interchanges on the motorway.

Further background guidance on interchange spacing is provided in:

- Austroads Guide to Traffic Management (AGTM) Part 6: Intersections, Interchanges and Crossings (Austroads, 2017).
- Austroads Guide to Road Design (AGRD) Part 4C: Interchanges (Austroads, 2009).
- VicRoads Supplement to the Austroads Guide to Road Design Part 4C – Interchanges (VicRoads, 2010).
- Austroads Guide to Smart Motorways (AGSM) (Austroads, 2016) which provides further guidance similar to the information in this section.

3.6.2 Design Considerations

The location and spacing of motorway interchanges is determined by a number of factors, including:

- Road network requirements for motorway accessibility, interconnectivity and traffic distribution.
- Surface road functionality and strategic connections including their capacity.
- Proximity of surface roads relative to motorway-to-motorway interchanges.
- Suitability of terrain and physical interchange characteristics, including horizontal and vertical alignment, etc.
- Ramp configurations and spacing between ramp tapers.

3.6.3 Ramp Spacing

The primary determinant of interchange spacing is not the distance between the centrelines of successive crossroads, but the combination of ramp design configurations (entry and exit ramps), the interchange form associated with each crossroad as well as the distance between ramps required for safety and efficient traffic operation.

Some jurisdictions may vary in their definition of 'ramp spacing'. The definition in this Guide for mainline 'ramp spacing' between an entry ramp and a downstream exit ramp is consistent with the definition provided in Austroads Guide to Traffic Management (AGTM) Part 6: Intersections, Interchanges and Crossings (Austroads, 2017)

- **Ramp spacing** (also denoted as 'L' in AGTM Part 6: Table 6.3) is the distance (along the mainline) measured between the gore areas, i.e. the point at each entry/exit to which the left edge line of the freeway and the right edge line of the ramp converge (refer Figure 3-6).

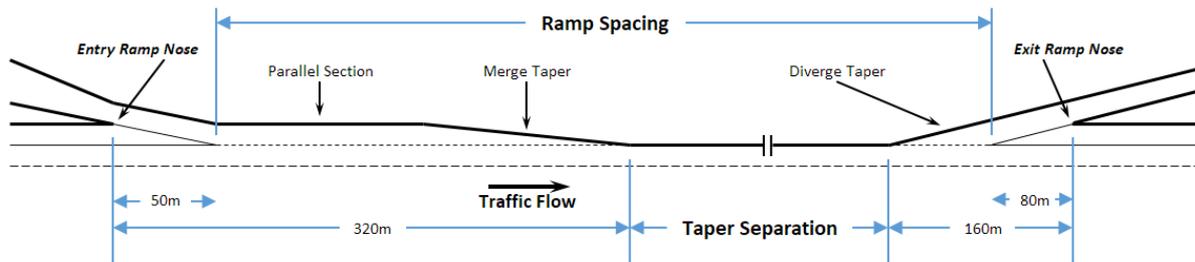


Figure 3-6: Definition of 'Ramp Spacing' and Taper Separation

The distance shown as Taper Separation in Figure 3-6 is provided to clarify the terminology used by practitioners when considering separation of ramps and ramp elements. Depending on the ramp entry / exit arrangements and lane configurations between interchanges (e.g. provision of auxiliary lanes between ramps), taper separation may not always be a design element that needs to be considered. Separation should also consider the safety factors discussed in Section 3.6.3.3.

The interchange location and physical spacing in the urban motorway context shall consider the matters above, as well as the combination of factors in Sections 3.6.3.1 to 3.6.3.5 relating to ramp geometry and ramp spacing. Further guidance relating to ramp access arrangements is also in Section 3.7.

3.6.3.1 Entry Ramps Geometric Design and Operation

The length and geometric layout of the entry ramp, including:

- The length from the surface road to the ramp nose, including the desirable vehicle storage at the ramp metering signals for the design (and/or ultimate) traffic volume – refer Section 6.3.
- The length of the merge area between the metering stop line and the ramp nose that considers the number of lanes at the stop line in relation to the mainline / ramp entry layout at the nose – refer Sections 6.5 to 6.8.
- The mainline / ramp entry layout configuration (refer Section 3.7.2).
- The length of the acceleration and merge taper(s) entering the mainline (refer VicRoads Supplement to Austroads Guide to Road Design Part 4C – Interchanges).
- The overall ramp length and acceleration length downstream of a metering stop line need to consider ramp grades and their impacts on vehicle performance, especially trucks. Complex or constrained locations may require steep upgrades, sometimes up to 6%. Refer to Section 6.5.2 for additional considerations.

3.6.3.2 Exit Ramps Geometric Design and Operation

The length and geometric layout of the downstream exit ramp, including:

- The mainline / ramp exit layout configuration (refer Section 3.7.3).
- The length of the exit ramp configuration for traffic leaving the mainline (refer VicRoads Supplement to Austroads Guide to Road Design Part 4C – Interchanges (2010)) including the length of the diverge taper from the mainline.
- Length of the exit ramp from the ramp nose to the surface road, including the deceleration distance and vehicle queuing at the exit ramp intersection (refer Chapters 8 and 9).

3.6.3.3 Ramp Spacing for Traffic Safety

The relative crash risk of closely spaced entry and exit ramps has been documented in (NCHRP Report 687, 2011) and in (NCHRP Report 785, 2014). The research conducted identified a consistent trend that shorter ramp spacing is generally associated with higher crashes along the mainline in between entry and exit ramps.

When ramp spacing values in the NCHRP reports are adjusted (for metrication and rounding), the safety implications and conclusions based on a single lane merge followed by a single lane diverge (as per Figure 3-6) are:

- The preferred minimum taper separation (between merge and diverge tapers) is 340 metres or more to achieve maximum operational safety.
- With taper separation less than 340 metres, the crash risks increase.

The research included in (NCHRP Report 687, 2011) also indicates that the presence of an auxiliary lane corresponds to approximately 20% fewer crashes for given levels of ramp spacing and traffic volume. Refer to Sections 3.7.4 and 4.3.2 for further information when considering implementation of auxiliary lanes.

3.6.3.4 Ramp Spacing for Traffic Operations

Turbulence occurs in the traffic stream as density increases and as motorists weave and change lanes between interchanges to position themselves for the desired movements downstream. Therefore, when considering interchange and ramp spacing, consideration shall be given to the magnitude of entry ramp and exit ramp traffic volumes as well as the segment capacity and operation of the weaving and lane changing areas.

Further guidance on analysis and functional design assessment is provided in Section 4.3.2.

3.6.3.5 Ramp Spacing for Exit Ramp Signage

The Left Lane advance exit direction sign for urban exit ramps is typically 500 metres prior to the exit. It is desirable that this be located in the taper separation area clear of merging and diverging manoeuvres.

3.7 Ramp-related Access Arrangements

3.7.1 Context

The design of interchanges and ramps that provide access to the mainline carriageway(s) has traditionally included an exit ramp and entry ramp forming a diamond interchange or similar layout. In some cases other non-direct ramp configurations, or separate ramps for left and right turning traffic from the surface road may be utilised, subject to the design volumes involved and availability of land. It is noted that some ramp configurations, such as loop ramps, can have impacts on safety and capacity due to their constraining geometric features (e.g. low radii combined with steep grades).

In challenging urban environments or where motorway facilities require upgrading to accommodate increasing traffic demands, complex access arrangements may be needed to adequately address traffic issues and ensure satisfactory operation after construction. Changes in design practice focus specifically on minimising mainline turbulence and maximising operational safety and capacity, particularly for motorways in high volume urban environments. Along most motorways there will be a mix of interchange and ramp types depending on the traffic demands and/or interchange locations.

In the context of increasing traffic demand along a route, older motorway facilities which may have performed satisfactorily in the past with lower volumes, may not be suitable for upgrading in their current form due to layouts needed to accommodate larger volumes, e.g. spacing of interchanges in the past may have accommodated merging, weaving and exiting traffic, but to operate satisfactorily with heavy demands into the future, ramp braiding, CD roads, extended ramps or other combinations of improvement may be needed.

The design and operation of ramps and longitudinal ramp-related access arrangements in this chapter also need to be considered in the context of the principles in later chapters:

- Entry ramps: Chapters 6 and 7.
- Exit ramps: Chapter 9.

3.7.2 Mainline / Ramp Entry Layout Configurations

Entry ramp merging and lane changing manoeuvres when entering the mainline can create turbulence which can affect flow stability, safety and capacity. Appropriate entry layout designs need to be chosen that will enable the mainline and entry ramps to operate satisfactorily after construction is completed.

Typical mainline / ramp entry layouts applicable to various maximum ramp volumes are provided in Table 3.1. This table should be used for selecting an appropriate geometric layout at the ramp nose and downstream of the entry and is *VicRoads supplementary information to be used in place of equivalent information in Austroads Guides*. There is a need to adjust volumes for heavy vehicles to determine passenger car units (PCU), and for this purpose, it could generally be assumed that each truck is equivalent to 2 cars.

In applying the ramp volume values in Table 3.1, it should not be assumed that they can actually be achieved in practice. Downstream mainline design, including the ability to accommodate ramp volumes, is subject to the Design Volume / MSFR analyses outlined in Sections 4.3 and 4.4.

The values in Table 3.1 for mainline / ramp entry may also assist in identifying an appropriate ramp layout for ramp metering when considering the ramp discharge capacity, ramp storage, and the location of the stop line (refer Chapter6).

A number of design iterations may be needed to determine the best combination for entry ramp and mainline / ramp entry configurations, particularly where high ramp volumes are involved and added lanes on the mainline may need to be considered.

Where an added lane is provided at an entry ramp, this should continue downstream until capacity analysis demonstrates that a lane reduction and resulting capacity decrease can accommodate the flow at that location.

Ramp Description	Entry Ramp Traffic Volume (pcu/h) ^(1,3)
Single lane at entry ramp nose with merge	≤ 1200
Single lane at entry ramp nose with an added lane on the mainline	≤ 1800
Two lanes at entry ramp nose including an added lane on the mainline	1500 to 2700
Two exclusive entry lanes with two added lanes on the mainline	2700 to 2-Lane MSFR Equiv. ⁽²⁾

Source: Based on (Austroads, 2016), Table 7.2. Values and descriptions differ based on consideration of downstream merge / added lane configuration and VicRoads operational experience.

Note 1: Regarding the number of lanes on the ramp itself, refer to VicRoads Supplement to the Austroads Guide to Road Design Part 4C – Interchanges (Table V5.1) and further considerations for ramp storage outlined in this Guide.

Note 2: May only be achievable at motorway-to-motorway entry ramps. Refer to Volume 1, Part 3 for MSFR value(s).

Note 3: This table shall be used in place of AGTM Part 6 (Austroads, 2017): Table 6.2 and AGSM (Austroads, 2016): Table 7.2

Table 3.1: Indicative mainline / ramp entry layouts

3.7.3 Mainline / Ramp Exit Layout Configurations

Lane changing and diverging manoeuvres of traffic leaving the mainline can create turbulence which can affect flow stability, safety and capacity. Appropriate layouts need to be chosen in design that will enable the mainline diverge areas at ramp exits or commencement of CD roads, etc., to operate satisfactorily after construction is completed.

Typical mainline / ramp exit layouts applicable to various maximum ramp volumes are provided in Table 3.2 and should be used for selecting an appropriate geometric layout. However, it should not be

assumed that the ramp volume values in Table 3.2 can actually be achieved. Mainline design is subject to the analyses outlined in Sections 4.3 and 4.4. Exit ramp designs and layouts are also subject to the requirements in Chapter 9.

A number of design iterations may be needed to determine the best combination for mainline / ramp exit configurations, particularly where high ramp volumes are involved and widening for an additional exclusive exit lanes on the mainline needs to be considered.

Ramp Description	Exit Ramp Traffic Volume (pcu/h) ^(1,3)
Single lane at exit ramp nose to a loop (typical loop ramp capacity)	≤ 900
Single lane at exit ramp nose (non-loop alignment)	≤ 1500
Two lanes at exit ramp nose (includes exclusive left lane plus diverge from the adjacent through lane for exiting traffic)	1500 to 2700 ⁽²⁾
Two exclusive exit lanes	2700 to 2-Lane MSFR Equiv. ⁽²⁾

Source: Based on (Austroads, 2016), Table 7.3

Note 1: Regarding the number of lanes on the ramp itself, refer to VicRoads Supplement to the Austroads Guide to Road Design Part 4C – Interchanges (Table V5.1).

Note 2: May only be achievable at motorway-to-motorway entry ramps. The transition lengths and development of additional lanes shall enable capacity to be developed for effective operation at the ramp volumes indicated – refer VicRoads Supplement to the Austroads Guide to Road Design Part 4C – Interchanges. Refer to Volume 1, Part 3 for MSFR value(s).

Note 3: This table shall be used in place of AGTM Part 6 (Austroads, 2017): Table 6.2 and AGSM (Austroads, 2016): Table 7.3.

Table 3.2: Indicative mainline / ramp exit layouts

3.7.4 Auxiliary Lanes

An auxiliary lane is an additional mainline lane between interchanges that provides for weaving and other lane changing movements associated with entering and exiting traffic. A sketch showing a typical auxiliary lane arrangement is in Figure 3-7.

The auxiliary lane may also be used for short local trips where traffic does not need to enter the continuing through lanes. Further guidance relating to analysis is provided in Section 4.3.2.3.

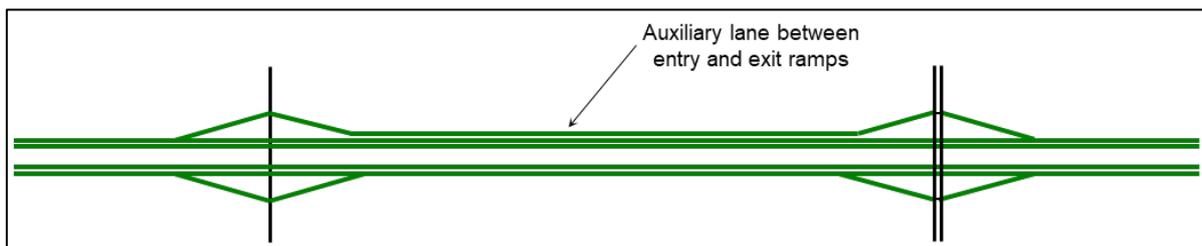


Figure 3-7: Example of Auxiliary Lane between Interchanges

In some situations, an extended auxiliary lane may be provided that continues through an interchange and terminates further downstream. This can facilitate lane changing and weaving manoeuvres associated with multiple closely spaced interchanges. Care is required in determining the appropriate termination location and treatment of an auxiliary lane in order to limit turbulence and avoid the formation of regular and strong operational bottlenecks. Refer to the discussion in Section 4.3.2.

3.7.5 Collector-Distributor (CD) Roads

Collector-distributor (CD) roads are longitudinal carriageways used to separate mainline through traffic movements from the entering and exiting movements at service interchanges. CD roads

provide a localised ramp access arrangement, generally for a CMC, but have a different length and purpose when compared to the strategic function of a CMC in providing service interchange access in association with a SLAC (refer separated mainline carriageway arrangements in Section 3.5).

A sketch showing a typical CD road arrangement is in Figure 3-8. They may need to be used in the following situations:

- To combine ramp movements where it is not feasible to provide direct access to the mainline, e.g. due to physical or space limitations.
- To combine ramp movements due to the close spacing of entry and exit ramp tapers, and hence minimise weaving movements on the mainline. In this case the auxiliary lane may also cater for short local trips where traffic does not need to enter the mainline.
- To reduce the number of exits / entries on the mainline and hence minimise turbulence.

Designs with a CD road would generally have the following characteristics:

- The CD road would exit the mainline in the form of a conventional exit ramp layout appropriate for the exiting volume.
- The CD road when entering a managed mainline would generally be controlled with ramp metering in a similar way to any other entry ramp. This is preferred as the point of control is closer to potential mainline bottlenecks. Alternatively, all ramps could be controlled individually where they enter the CD road. This latter control arrangement may need to be adopted if space is not available for the ramp signal layout where the CD road enters the mainline, e.g. space for localised auxiliary lanes at the Stop Line.
- Entry ramps entering the CD road may, or may not, need to be controlled with ramp metering subject to the criteria for ramp metering in Volume 2 Part 1.
- Exit and entry arrangements need to cater for combined flows of all interchanges serviced.
- CD roads may operate at the same, or a lower design speed, relative to the mainline.

In some designs a CD road may also form part of an extended ramp or ramp braiding.

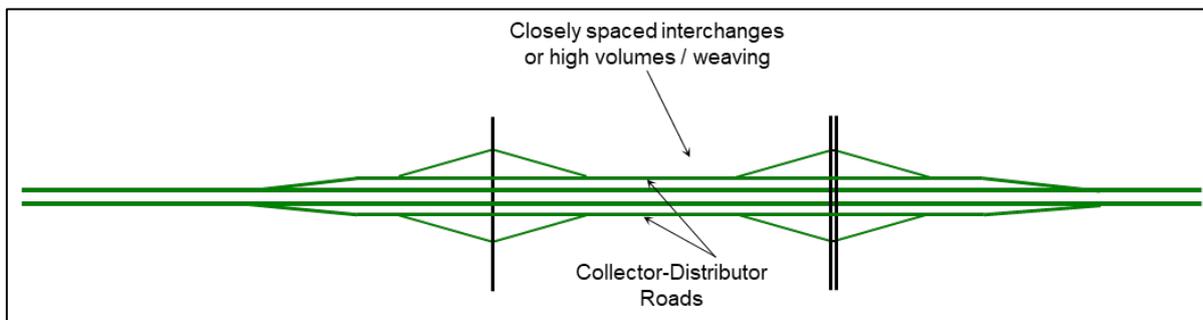


Figure 3-8: Example of Collector-Distributor Roads

3.7.6 Ramp Braiding

Ramp braiding refers to grade separation between ramps so that weaving manoeuvres on the mainline between entering and exiting movements can be minimised. This layout may need to be considered if there are closely spaced entry and exit ramps with high flows, and/or weaving manoeuvres (with / without an auxiliary lane) and flows in excess of an adjusted MSFR – refer Section 4.3.2.9).

A sketch showing a typical ramp braiding arrangement is in Figure 3-9. In some designs ramp braiding may also form part of an extended ramp or a CD road.

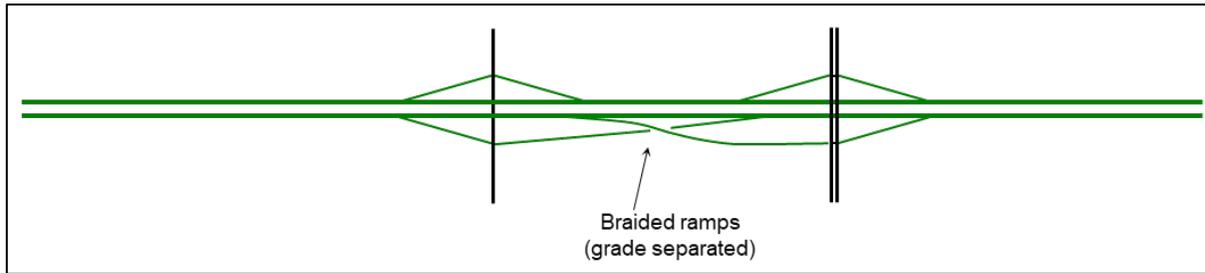


Figure 3-9: Example of Braided Ramps

3.7.7 Extended Ramps (ERs)

Extended ramps for entry or exit movements form a separate longitudinal carriageway in the following situations:

- Where non-standard connections are needed to the surface road network or there is difficulty providing a conventional ramp due to the physical location of an adjacent interchange.
- Where vertical or horizontal alignments or constraints inhibit the ability to provide the necessary entry / exit geometry at a conventional location.
- To locate a ramp connection to the mainline in a position to avoid a weaving situation.
- In some designs an extended ramp may be combined with braiding or form part of a CD road.
- For an entry ramp if there are design problems associated with the ramp length to suit ramp metering signals, e.g. storage length.
- To provide an alignment that facilitates appropriate entry merge speeds due to ramp grades or curved geometry.
- For an exit ramp if there are design problems associated with the ramp length for accommodating high volumes and/or where long queues may extend back from the interchange intersection.

A sketch showing a typical extended ramp arrangement is in Figure 3-10.

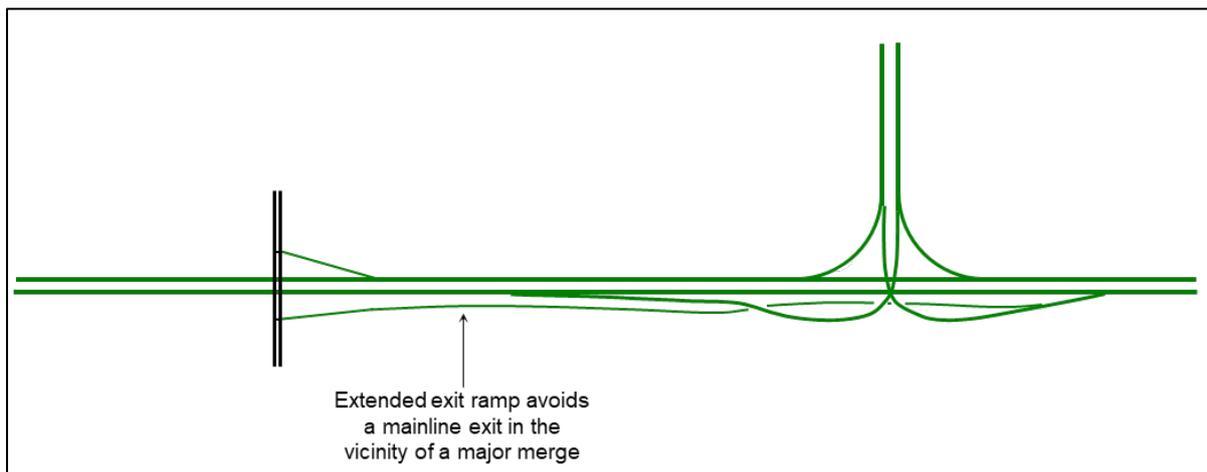


Figure 3-10: Example of an Extended Ramp

Volume 2: Design Practice
Part 3: Motorway Planning and Design

Chapter 4: Mainline Analysis and Functional Design



4 Mainline Analysis and Functional Design

4.1 General Process

4.1.1 Overview

The aim of Managed Motorway design is to provide infrastructure with balanced capacity along the motorway to minimise critical bottlenecks, and where mainline turbulence is minimised by providing adequate capacity for managing traffic demands. This includes good mainline geometry, consideration of segments between and within interchanges, lane changing/weaving areas, entry ramp configurations and diverges to exit ramps.

Managed motorways design requires a system approach with investigation along a significant length of motorway to gain an overall understanding of motorway performance, infrastructure characteristics and new potential bottleneck locations affecting the design of the mainline as well as the design of entry ramps to suit coordinated ramp metering signals. There is also a need to understand if upstream bottlenecks being addressed either as part of the current, or a future project, will release increased flows into downstream segments of the motorway.

An overview of managed motorway components which are part of functional design is in Figure 4-1.

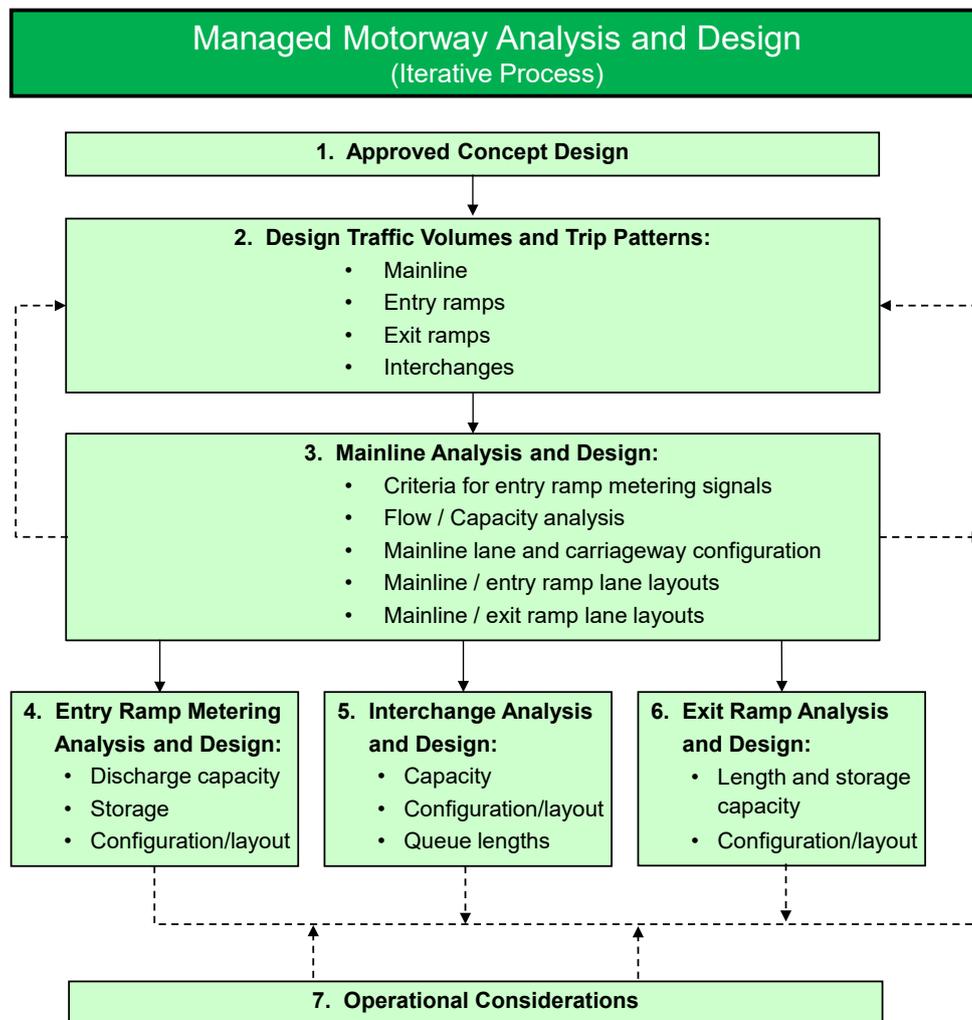


Figure 4-1: Managed Motorway Functional Design Components

4.1.2 Iterative Design Process

The typical Managed Motorway analysis and design process shown in Figure 4-1 indicates that an iterative process is generally required. This is necessary as feasibility or decisions relating to one component can have implications for other components of analysis and design, as well as cost.

In some cases a number of iterations are required as project scope and design are formulated, and in response to the broader context as additional information becomes available. The iterative process includes refining of design volumes developed during the concept design process as well as refining the level of detail in the concept design.

Final peak hour design traffic volumes should be rechecked at the stage when functional designs are near completion to ensure consistency of mainline lane configurations, entry ramp layouts, exit ramp layouts and that interchange operational designs are satisfactory.

For motorway upgrade projects, a general principle is that the ultimate motorway needs should be determined first. After the ultimate project details and analyses are finalised, any initial and subsequent staging options are considered to ensure satisfactory operation in the short term for successful Managed Motorway outcomes (refer Section 3.3.2).

4.1.3 Outline of Design Components

This chapter provides guidance relating to Components 1 and 2 in Figure 4-1 and includes determination of design traffic volumes, mainline analysis and design, and layouts for entry and exit ramps at the mainline. The criteria for providing ramp metering signals for mainline management is provided in Volume 2, Part 1.

The analysis and design process for a coordinated ramp signals system not only considers the essential provisions of ramp storage and number of discharge lanes. It also considers the ability of the mainline to operate as a managed motorway with optimised outcomes.

The following chapters provide design guidance relating to components 3, 4 and 5 in Figure 4-1:

- Chapter 6: Entry ramp analysis and design for ramp metering signals
- Chapter 7: Motorway-to-motorway entry ramp metering signals design
- Chapter 8. Surface road interchanges and access management
- Chapter 9: Exit ramp design and management

Information relating to operation of ramp metering signals is provided in Volume 2, Part 2.

The analysis and choice of functional designs for mainline carriageways and ramps in this Guide needs to be considered according to motorway design principles that will contribute towards optimising operation of the network.

Reference should also be made to the Austroads Guide to Traffic Management, Austroads Guide to Road Design and the VicRoads Supplements to the Austroads guides. While analysis and design may focus on the optimisation of designs for operations, safety outcomes must also be checked across all components throughout all design stages.

A factor allowed for in the analyses is the significant difference between 'fully managed' mainline capacity and 'unmanaged' capacity for motorway segments. The full benefit of managed motorway control only comes with a route treatment that requires control of all entering traffic, i.e. the coordinated system needs to be able to balance demand and equity of access across a number of entry ramps upstream of a motorway segment.

Therefore, capacity does not change from 'unmanaged' to 'managed' capacity at the first ramp with ramp signals. Mainline segments near the start of a ramp metering system are within a Partially Managed Transition Zone (PMTZ), i.e. it is generally not able to operate at the full level of 'managed' capacity, although there will still be some benefit. The PMTZ capacity has been included as part of

the analysis process. Furthermore, if any entry ramp within a system is not controlled, the downstream capacity reverts back to 'unmanaged' capacity and then requires several controlled ramps to develop the full level of 'managed' operation.

4.2 Design Volumes (Mainline and Ramps)

The general processes for determining design flows for consideration in design is provided in Section 3.1 in the context of planning and concept design. The refinement of forecast traffic volumes for the analysis and functional design processes (based on existing data and/or strategic traffic modelling) is an essential first step in functional design.

Realistic and appropriate design volumes are essential to ensure appropriate motorway design of:

- Mainline and lane configurations, including volume relative to design capacity
- Entry ramp discharge capacity, storage and ramp layout configurations
- Exit ramp length, capacity and layout configurations
- Interchange capacity and layout

Guidance relating to design volumes and identifying other matters relevant to the design for retrofitting existing freeways / motorways is provided Section 3.2. Guidance relating to motorway capacity upgrade projects or a new motorway is in Section 3.3.

4.3 Mainline Capacity Analysis and Design

During the concept design process (refer Chapter 3), high level volume/capacity analysis is carried out as part of the strategic modelling process.

Motorway analysis during the functional design process, including upgrading of existing motorways, focusses on a more detailed analysis process that compares forecast design volumes with Maximum Sustainable Flow Rates (MSFR).

Capacity analysis and design using MSFR provide a higher level of understanding of how the project will perform after construction and ensure that adequate infrastructure is provided for the forecast traffic demands. MSFR should be used for capacity analysis and design rather than theoretical (or HCM) capacity values.

4.3.1 Maximum Sustainable Flow Rates for Mainline Design

The VicRoads Motorway Design Volume Guide provides guidance on maximum sustainable flow rates (MSFR) for Managed Motorway design (mainline carriageways and CD roads). These values are based on analysis of measured flows and the 1% probability of flow breakdown per 15 minute interval at active bottleneck locations on Melbourne's managed motorways. The values also reflect urban motorway travel with closely spaced interchanges and shorter trips resulting in higher lane changing.

Tables in the Guide shown in the following pages provide values according to the number of mainline lanes and the percentage of trucks in the traffic stream.

A concept of passenger car equivalents (PCE) used in some capacity guides, including the HCM, is related to traffic behaviour due to the vehicle mix (presence of heavy vehicles) in the traffic flow.

These factors include:

- Physical space taken up by a large vehicle;
- Longer and more frequent gaps in front and behind heavy vehicles;
- Speed of vehicles in adjacent lanes and their spacing.

In this capacity analysis heavy vehicles are converted into an equivalent number of passenger cars to achieve a consistent measure of flow. The MSFR values below reflect operational values to account for the presence of heavy vehicles.

MSFR values in Volume 1, Part 3 are to be used for analysis and design of motorway sections for managed and unmanaged scenarios. For some motorway features the MSFR value may need adjustment according to guidance in Section 4.3.2. The MSFR values provided in Table 4.1 replicate Tables 4 to 7 in Volume 1, Part 3 of this Guide.

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	4,175	3,975	3,800	3,625	3,475	3,325	3,200
3	6,050	5,775	5,525	5,250	5,050	4,850	4,625
4	7,800	7,450	7,125	6,775	6,500	6,225	5,975
5	9,275	8,875	8,475	8,050	7,750	7,425	7,100

Table 4: Carriageway MSFR design values (veh/h) - managed motorways (gradient s <= 2%)

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	3,950	3,775	3,625	3,450	3,300	3,175	3,025
3	5,750	5,500	5,250	5,000	4,800	4,600	4,400
4	7,400	7,075	6,750	6,425	6,175	5,925	5,675
5	8,800	8,425	8,050	7,650	7,350	7,050	6,750

Table 5: Carriageway MSFR design values (veh/h) - managed motorways (2% < gradient s <= 3%)

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	3,750	3,600	3,425	3,250	3,125	3,000	2,875
3	5,450	5,200	4,975	4,725	4,550	4,350	4,175
4	7,025	6,700	6,400	6,100	5,850	5,600	5,375
5	8,350	7,975	7,625	7,250	6,975	6,675	6,375

Table 6: Carriageway MSFR design values (veh/h) - managed motorways (3% < gradient s <= 4%)

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	3,450	3,300	3,150	3,000	2,900	2,775	2,650
3	5,025	4,800	4,575	4,375	4,200	4,025	3,850
4	6,475	6,175	5,900	5,625	5,400	5,175	4,950
5	7,700	7,350	7,025	6,700	6,425	6,150	5,875

Table 7: Carriageway MSFR design values (veh/h) - managed motorways (4% < gradient s <= 5%)

Table 4.1: Managed Motorway Sections - Maximum Sustainable Flow Rates

The MSFR design values for tunnel sections on managed motorways (Table 8 to Table 11) are shown in Table 4.2.

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	3800	3650	3475	3325	3175	3050	2925
3	5725	5475	5225	4975	4775	4575	4375
4	7625	7300	6950	6625	6350	6100	5825

Table 8: Tunnel MSFR design values (veh/h) – managed motorways (gradient s <= 2%)

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	3625	3450	3300	3150	3025	2900	2775
3	5425	5200	4950	4725	4525	4350	4150
4	7250	6925	6600	6300	6050	5800	5550

Table 9: Tunnel MSFR design values (veh/h) – managed motorways (2% < gradient s <= 3%)

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	3425	3275	3125	2975	2850	2750	2625
3	5150	4925	4700	4475	4300	4125	3925
4	6850	6550	6275	5975	5725	5475	5250

Table 10: Tunnel MSFR design values (veh/h) – managed motorways (3% < gradient s <= 4%)

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	3150	3025	2875	2750	2650	2525	2425
3	4750	4550	4325	4125	3950	3800	3625
4	6325	6050	5775	5500	5275	5050	4850

Table 11: Tunnel MSFR design values (veh/h) - managed motorways (4% < gradient s <= 5%)

Table 4.2: Managed Motorway Tunnel Sections - Maximum Sustainable Flow Rates

The MSFR design values for unmanaged motorways (Table 12 to Table 15) are shown in Table 4.3. These values for unmanaged motorways generally indicate a reduction of 15% for design relative to a managed motorway.

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	3,550	3,400	3,225	3,075	2,950	2,825	2,700
3	5,150	4,925	4,700	4,475	4,300	4,125	3,925
4	6,625	6,325	6,050	5,750	5,525	5,300	5,075
5	7,875	7,525	7,200	6,850	6,575	6,300	6,025

Table 12: Carriageway MSFR design values (veh/h) – unmanaged motorways (s <= 2%)

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	3,375	3,225	3,075	2,925	2,800	2,700	2,575
3	4,875	4,675	4,450	4,250	4,075	3,900	3,725
4	6,300	6,025	5,750	5,475	5,250	5,025	4,825
5	7,475	7,150	6,825	6,500	6,250	6,000	5,725

Table 13: Carriageway MSFR design values (veh/h) - unmanaged motorways (2% < gradient s <= 3%)

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	3,200	3,050	2,900	2,775	2,650	2,550	2,450
3	4,625	4,425	4,225	4,025	3,850	3,700	3,550
4	5,950	5,700	5,450	5,175	4,975	4,775	4,550
5	7,100	6,775	6,475	6,175	5,925	5,675	5,425

Table 14: Carriageway MSFR design values (veh/h) - unmanaged motorways (3% < gradient s <= 4%)

Number of lanes	HGV Percentage (%)						
	0%	5%	10%	15%	20%	25%	30%
2	2,950	2,800	2,675	2,550	2,450	2,350	2,250
3	4,275	4,075	3,900	3,700	3,550	3,425	3,275
4	5,500	5,250	5,025	4,775	4,600	4,400	4,200
5	6,550	6,250	5,975	5,675	5,450	5,225	5,000

Table 15: Carriageway MSFR design values (veh/h) - unmanaged motorways (4% < gradient s <= 5%)

Table 4.3: Un-Managed Motorway Sections - Maximum Sustainable Flow Rates

4.3.2 Adjustments to MSFR Values in Design

4.3.2.1 Adjustment factors included in MSFR Values

The MSFR values above already account for some segment characteristics where minimal impact on capacity has been measured. Although some other capacity guides, e.g. Austroads and HCM, would apply adjustments for these factors, it is not necessary when using the MSFR values. These include:

- Segments with 80 km/h speed limits (although this may change in the future with regular revisions of MSFR values)
- Segments with all lane running (no shoulder or emergency stopping lane), i.e. low lateral clearance
- Segments with narrow lanes

However, on segments with combined factors, an MSFR value less than the full applicable MSFR may need to be considered.

4.3.2.2 Other adjustment factors that may need to be applied

The MSFR values in Section 4.3.1 may need to be adjusted for site specific road characteristics on some motorway segments. These could include factors listed in Volume 1, Part 3: Tables 1-2 and 1-3 where traffic or route characteristics will impact the motorway’s capacity. Furthermore, the applicable MSFR value (based on managed operations) will also vary according to the extent of managed control with ramp metering, e.g. for a partially managed motorway, or near the start of a Managed Motorway section. Further guidance relating to this matter is provided in Section 4.4.5.

The following sections provide some 'rules of thumb' for motorway segments where MSFR values should generally be reduced to a figure less than the values in Table 4.1 to Table 4.3. Some of these factors need further research.

4.3.2.3 Auxiliary Lanes

Auxiliary lanes between interchanges cater for entry and exit flows so are generally underutilised relative to through lane volumes. The additional capacity available from the auxiliary lane is used by weaving manoeuvres and short local trips. Therefore, from an analysis perspective, the auxiliary lane is not available for through traffic movements. Although an auxiliary lane may be used by motorists attempting to overtake and get ahead in the traffic, this does not increase capacity and may increase turbulence due to lane changing and re-entry into the continuing lanes. Further commentary regarding auxiliary lanes is in (Volume 1, Part 3: Section 2.7).

For analysis the following options may be considered, subject to the length of the lane and the magnitude of the movements involved:

- Assume that the maximum flow in the auxiliary lane is the exiting volume which accounts for short trips in the auxiliary lane between two interchanges, as well as through traffic changing lanes to exit. Other entering traffic will change lanes and use the continuing lanes.
- A further adjustment to through lane MSFR values may be necessary with high weaving manoeuvres, particularly where a high entering volume needs to change lanes into the continuing lanes, or if there is a high exiting volume changing lanes.
- Where the auxiliary lane continues through several interchanges, some small additional capacity may be realised for through traffic, subject to allowance for the volumes of exiting flows and the number of interchanges serviced.

To minimise turbulence and the potential for creating a critical bottleneck area, the geometric layout at the end of an auxiliary lane needs consideration of the length available for lane changing as well as the magnitude of entering and exiting traffic volumes. Guidance relating to the use and analysis of a lane drop or an exclusive exit lane is provided in Sections 4.3.2.4 and 4.3.2.5 respectively.

4.3.2.4 Lane Drops

The MSFR design guidance for lane drops is based on midblock capacity studies quoted in the HCM for reduced lane layouts at long term construction zones (indicating a maximum of 1500 veh/h/ln across all lanes for various lane drop combinations), as well as studies by (Bertini R., 2004) and (Margreiter, 2017) on the effects of lane closures on traffic flow, and which indicate that capacity with a lane closure is in the order of 1400 to 1500 veh/h/ln in each of the continuing lanes after the lane drop.

In the managed motorway context, the MSFR design guidance is based on the limited ability to manage the uncontrolled nature of concentrated arrivals and merging of traffic, i.e. conditions are similar to an unmanaged merge.

A lane drop on a mainline segment or downstream of an exit ramp generally operates as an unmanaged merge where lane changing and clustering of vehicles can cause turbulence, instability and flow breakdown (refer layout in Figure 4-2), particularly where carriageway volumes approach the MSFR. During operations, these lanes can also be used by aggressive motorists overtaking slower moving traffic. In these situations the concentrated arrival of merging traffic is unpredictable and hard to manage, even in the context of a managed motorway.

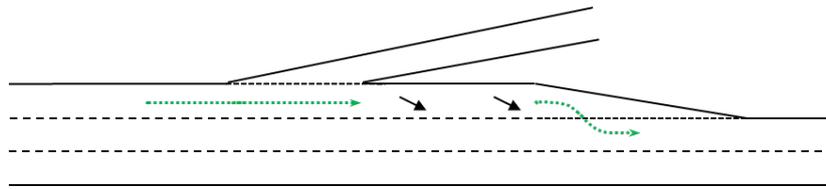


Figure 4-2: Example of Traffic Lane Changing at a Lane Drop

For lane drop layouts either between interchanges or downstream of an exit, the MSFR to be applied for the segment with the lane drop is to be not greater than 90% of the applicable MSFR (unmanaged or managed) for the downstream continuing lanes.

Generally, these layouts are only appropriate where there is a terminating auxiliary lane and traffic from the entry ramp immediately upstream requires a longer distance to complete the lane changing manoeuvre. Other locations may be suitable subject to the adequacy of the MSFR reduction and the Volume / MSFR calculation.

Where lane drop analysis indicates a critical bottleneck situation would be created, and particularly where there is a high exit volume, an exclusive exit lane (refer Section 4.3.2.5) should generally be adopted. Alternatively, extending the terminating lane further downstream to another interchange may need to be considered if analysis indicates that capacity is a problem immediately downstream of the exit ramp.

4.3.2.5 Exclusive Exit Lanes

A mainline lane reduction that occurs in the form of an Exclusive Exit Lane (EEL) as shown in the typical layout in Figure 4-3, enables lane changing from the terminating lane to be spread over a longer distance where there is greater capacity (more lanes on the approach) to facilitate the lane changing. This layout also avoids a sudden lane drop that results in an uncontrolled merge with lower capacity.

In a managed context this layout is preferred as it improves the ability to manage flows as a whole, and particularly in areas where turbulence can occur.

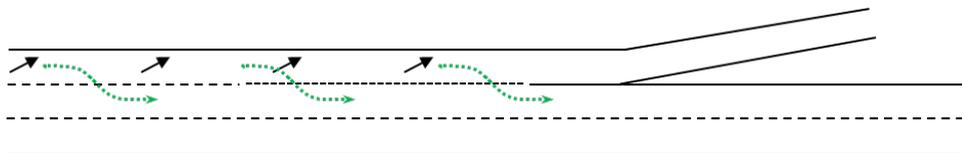


Figure 4-3: Example of Traffic Lane Changing with an Exclusive Exit Lane

An EEL means that the left lane(s) may be underutilised. Therefore, the maximum MSFR value (capacity) applied to the terminating lane(s) during analysis should be no greater than the design exit volume. The analysis examples shown in Figure 4-5 and Figure 4-6 include a reduced MSFR for the exclusive exit lane. In some situations, the MSFR of adjacent through lanes may also need to be adjusted (upstream of the exit) if significant lane changing is to occur, or if there is only a short lane-changing distance available.

For the remaining through lanes beyond the exit that carry the continuing traffic downstream, no MSFR reduction is generally needed for design. Although the reduced cross section capacity downstream of the exit ramp has greater capacity than either a separate lane drop after the exit (as in Figure 4-2) or at some other mainline location, the reduced cross section may still be a critical bottleneck area. Therefore, vehicle detection in this area downstream of the exit ramp nose is essential.

4.3.2.6 Unmanaged Tunnels

Tunnel designs need to ensure a high level of control for operation along the mainline to promote consistent vehicle speed and to minimise the potential for slow moving traffic, flow breakdown and congestion.

For unmanaged tunnel sections, 85% of the applicable MSFR value for a managed tunnel should generally be adopted for analysis.

4.3.2.7 Sections at the Start of a Managed System

At the beginning of the managed system, the full value of managed capacity is not achieved until some distance into the system, i.e. to manage a critical bottleneck there may need to be a number of controlled ramps contributing to the necessary traffic management of managed capacity. Further guidance related to analysing this 'Partially Managed Transition Zone' (PMTZ) is provided in Section 4.4.5.

4.3.2.8 Managed Sections with an Uncontrolled Ramp

A section of Managed Motorway with an unmanaged ramp effectively has unmanaged capacity at that point and should generally be avoided. This is because the system capacity is determined by the weakest link, and if flow breakdown occurs it not only impacts flow at that location, but generally forms a slow moving queue that will extend many kilometres upstream and thus reduce the available flow and speed on many upstream segments.

If there are sections of a Managed Motorway with an uncontrolled ramp, the analysis of downstream sections should generally be based on unmanaged capacity at that ramp and then with incremental capacity increases in the partially managed downstream sections based on guidance provided in Section 4.4.5. Coordinated ramp metering designs that include an uncontrolled ramp(s) require approval by VicRoads Road and Traffic Design Department.

4.3.2.9 High Lane Changing Segments including Weaving

Lane changing on motorways is a factor that can impact operational performance. Many studies on lane changing have focused on developing models to describe and estimate lane changing behaviour and a few studies have empirically measured lane changing, although sample data is usually limited due to the difficulty collecting lane change data.

The MSFR values in Section 4.3.1 allow for 'normal' levels of lane changing (mandatory and discretionary) for the various defined motorway section characteristics. However, higher concentration of mandatory lane changing (also causing further balancing lane changing at flows close to capacity), causes further turbulence on those motorway segments, e.g. weave segments (as defined in the HCM) as well as segments where high entry ramp flows are followed by high exit ramp flows, particularly if these movements occur over a relatively short distance. In these cases a higher level / intensity of mandatory lane changing for some vehicles is required as well as lane changing to balance traffic across the available through lanes. Figure 4-4 shows an example where ramp and mainline flows are assumed and angled arrows are shown to demonstrate the typical nature and magnitude of lane changes required for entry / exit manoeuvres and to balance volumes across the carriageway.

It is acknowledged that there may be existing or new motorways where lower radius curves need to be included in the design with appropriate analyses. Until further evidence based information is available, a value of 90-95% of the applicable MSFR is desirable for curves less than 600 metres radius (based on Austroads Guide to Smart Motorways).

4.3.2.11 Mainline Special Use Lanes

Special use lanes generally have adverse traffic and safety benefits but are sometimes considered based on perceptions and/or policy reasons for:

- High occupancy vehicles, including buses and taxis.
- Cars only (no trucks).

Special use dedicated lanes for priority users (both in terms of vehicles and people) will generally negatively impact overall capacity and safety of the infrastructure. This is due to:

- Underutilisation of the special use lane.
- Turbulence and friction effects across the carriageway as a result of increased lane changing to access and utilise special use lanes.

Although a 'No Trucks' (cars only) lane may seem to have higher capacity than the other mainline lanes with trucks, this can be more than offset by reductions in capacity of the other lanes on facilities with high commercial vehicles due to increased truck percentages, as well as the lane changing and turbulence caused as motorists change lanes to/from the special use/restricted lane (refer Section 4.3.1).

A statistical study by (Varaiya & Kwon, 2008), of California's high occupancy vehicle (HOV) system (comprising 40% of the USA's managed lanes), indicated that HOV lanes suffer a 20% capacity penalty. Generally, it should not be assumed that the person-throughput per lane is higher with these facilities even during peak periods. Where high person-throughput values per hour/lane are to be assumed, this needs to be demonstrated from empirical data at the site or other comparative situations. Some jurisdictions have also reported significant increases in crash rates when these facilities are installed.

Therefore, it is preferable to optimise productivity and mainline flow / speed for all road users across all lanes in combination with a fully managed operational regime. If policy or specific direction requires special use lanes are to be provided on the mainline (i.e. on the median side of the carriageway accessible from adjacent lanes), a minimum 20% reduction of the relevant MSFR value shall be adopted for the cross section, or a greater reduction subject to analysis of anticipated usage. Alternatively, a separate dedicated carriageway could be considered that does not impact capacity for general traffic.

Where there is an intention to provide benefits for priority users, the priority measures should generally be implemented on the entry ramps (refer Section 6.8) and/or exit ramps at the respective interchanges.

4.3.2.12 Mainline / Entry Ramp Layout Configurations

Entry ramp merging and lane changing manoeuvres can create turbulence on the mainline which can affect mainline capacity. Appropriate layouts according to entry ramp flows need to be chosen that minimise turbulence in the merging areas as outlined in Section 3.7.2 above.

Where proposed mainline/entry ramp layouts do not meet the requirements of Section 3.7.2 it is expected that turbulence will result in reduced capacity and the MSFR for that segment should be adjusted accordingly.

4.3.2.13 Mainline / Exit Ramp Layout Configurations

Exit ramp diverging and lane changing manoeuvres can create turbulence on the mainline which can affect mainline capacity. Appropriate layouts according to exit ramp flows need to be chosen that minimise turbulence in the lane changing and diverging areas as outlined in Section 3.7.3.

Where proposed mainline/exit ramp layouts do not meet the requirements of Section 3.7.3 it is expected that turbulence will result in reduced capacity and the MSFR for that segment should be adjusted accordingly.

4.4 Mainline Design Volume / MSFR Analysis

4.4.1 Mainline Design Performance

An indicative analysis using a system approach along the route considering all mainline segments, exit ramps and entry ramps is able to indicate the adequacy of mainline lane configurations as well as locations of critical bottlenecks.

The overall objective of the analysis is to ensure a balance of flow relative to MSFR along the route, and to ensure that lane layouts are appropriate for the traffic flows anticipated, i.e. to develop or examine proposals for best performance outcomes after construction.

The ratio of the hourly design volume to the maximum sustainable flow rate (Volume / MSFR) is used as a measure of motorway performance during design, i.e. an indicator of anticipated traffic flow quality.

This measure of design adequacy and effectiveness is applied to all mainline segments based on the capacity of that segment considering a range of factors as discussed in Section 4.3. The analysis for considering the ratio of the hourly design volume to the maximum sustainable flow rate (Volume/MSFR) should also be applied to separated mainline carriageways and CD roads (refer Sections 3.5 and 3.7).

This measure is generally considered more useful compared to density or speed calculations used in some other methodologies, e.g. HCM. In some cases this route analysis may be carried out in parallel with micro-simulation or other investigations to check the adequacy of the project components and lane configurations relative to design traffic demand. In some locations with varying origin-destination or traffic volume patterns, volumes during the shoulder of the peak or other periods may need to be analysed and considered.

4.4.2 Performance Targets for Mainline Design

The Volume/MSFR ratio provides an indication of the possibility of flow breakdown and the likely challenges for satisfactory operation within the ramp metering system. It can also guide in decision making relating to which entry ramps are critical to operations of downstream sections of the motorway.

The performance target for design is a Volume/MSFR ratio of 1.0 (or 100% if expressed as a percentage), based on design MSFR values in Section 4.3, including appropriate adjustments.

Each motorway segment (between interchanges and within interchanges) should be evaluated to identify critical bottlenecks. In general terms, the bottleneck section with the maximum Volume/MSFR ratio, represents the worst case (weakest link) for the route as a whole.

4.4.3 Analysis Process

The purpose of the Volume/MSFR analysis is to ensure that the proposed mainline design can accommodate the design flows and to assist the designer in determining a Volume/MSFR balance along the route, i.e. where additional lanes or extending of lanes may be required or where removal of lanes could be accommodated within the design. The Volume/MSFR analysis should be part of

investigations at the planning or functional design stage to inform the scope of work and likely performance outcomes.

When the mainline and ramp flows have been determined, an analysis is required to compare the mainline flow with the capacity of the motorway at all mainline segments along the route, both between interchanges and within interchanges between exit and entry ramps.

The mainline evaluation carried out using a Volume/MSFR analysis assists in understanding the performance of the route (existing and/or proposed) relative to capacity, the balance of traffic flows along the motorway relative to capacity, and the location of critical bottlenecks as well as to identify the entry ramps in design which are more critical for achieving effective control and operations.

The analyses can assist in identifying contributing factors that could lead to flow breakdown and congestion, e.g. impact of reduced capacity due to weaving or a geometric feature. By the use of adjusted capacity values along the route according to segment characteristics, analyses can also contribute to understanding the viability and extent of proposed coordinated ramp metering.

The analyses generally need to be carried out for both the AM and PM peaks (may also need to consider the shoulder or inter-peak) as different, and sometimes worse, travel patterns can affect operational outcomes, particularly for circumferential routes or radial routes with destinations or high employment centres in the opposite direction to the normal peak direction of travel, e.g. shopping centres, industrial and freight centres, etc.

Consideration of the highest volumes during the day for ramp designs (entry and exit) may also affect ramp or interchange designs and may need to be considered as part of the iterative process.

4.4.4 Methodology

An indicative analysis methodology with development of a spreadsheet model relates the design volume to the MSFR on each segment along the route to identify locations of critical bottlenecks.

This assists in an understanding of the mainline flow performance which varies where circumstances change, e.g. the number of lanes and other factors affecting capacity, such as lane drops (between or within interchanges), steep upgrades etc., as well as the implications of entry ramp and exit ramp flows, e.g. high weaving areas.

The general process is to apply the principles outlined above to ensure maximum sustainable flow rates are not exceeded either at entry ramp merges or at other locations where physical characteristics reduce capacity. Examples of part of an indicative route analysis are provided in Figure 4-5 (analysis calculations) and Figure 4-6 (chart schematic). The analysis indicates oversaturation between I/C-1 and I/C-2 which needs to be considered in design and operations (refer to 4.4.7).

If a project includes a separated limited access carriageway (refer Section 3.5) or a collector-distributor road (refer Section 3.7), this will generally require analysis of those carriageways in parallel with the conventional mainline carriageway, including consideration of matching flows at the start and end of such facilities where they connect to the mainline.

Part 3: Motorway Planning and Design

Mainline Segment Inputs: Eastbound (Traffic Flow =>)

No. Mainline Continuing Lanes --> (Input Aux. & Excl. Exit Lanes below)	3	3	3	3	3	3	3	3	3	3	2	2	2	2
Motorway Contol:	Managed	Managed	Managed	Managed										
Grade:	Up to 2%	Up to 2%	Up to 2%	Up to 2%										
HGV %:	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Through Lanes: % of full MSFR	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	90% Lane drop	100%	100%	100%
MSFR (Through Lanes only)	5775	3578	3975	3975	3975									
MSFR per Through Lane	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1789	1988	1988	1988
Other Adjustments:														
Part. Man. Transition: % of MSFR	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
No. Auxiliary Lanes -->														
Aux. Lanes: % of through MSFR	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
No. Exclusive Exit Lanes -->														
EELs: % of through lane MSFR	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
MSFR (Managed)	5,775	3,578	3,975	3,975	3,975									
MSFR (Unmanaged)	4,909	4,909	4,909	4,909	4,909	4,909	4,909	4,909	4,909	4,909	3,041	3,379	3,379	3,379
AM Peak Volume / MSFR ratio:	74%	62%	76%	73%	91%	86%	86%	71%	83%	104%	102%	88%	94%	
PM Peak Volume / MSFR ratio:	102%	84%	109%	93%	101%	88%	88%	66%	88%	103%	105%	89%	98%	

Guide Motorway 2: Design Volumes & Layout - Managed

Total Lanes -->	3	IC 1		3	IC 2		3	IC 3		3	IC 4		3	IC 5		2	IC 6		2	2					
AM Peak	4,250	650	3,600	780	4,380	190	4,190	1,050	5,240	260	4,980	-	4,980	854	4,126	670	4,796	1,080	3,716	330	4,046	530	3,516	210	3,726
PM Peak	5,880	1,050	4,830	1,490	6,320	960	5,360	490	5,850	790	5,060	-	5,060	1,250	3,810	1,260	5,070	1,380	3,690	480	4,170	630	3,540	370	3,910
Eastbound (Traffic Flow =>)																									
Westbound (<= Traffic Flow)																									
AM Peak	5,468	900	4,568	1,232	5,800	800	5,000	570	5,570	800	4,770	-	4,770	1,000	3,770	1,300	5,070	1,700	3,370	420	3,790	800	2,990	510	3,500
PM Peak	4,099	700	3,399	950	4,349	200	4,149	961	5,110	500	4,610	-	4,610	1,200	3,410	560	3,970	1,200	2,770	380	3,150	500	2,650	350	3,000
<- Total Lanes	3	IC 1		3	IC 2		3	IC 3		3	IC 4		3	IC 5		2	IC 6		2	2					
AM Peak Volume / MSFR ratio:	95%	79%		100%	87%		96%	83%		83%	85%		88%	85%		95%	75%		88%						
PM Peak Volume / MSFR ratio:	71%	59%		75%	72%		88%	80%		80%	59%		69%	70%		79%	67%		75%						

Mainline Segment Inputs: Westbound (<= Traffic Flow)

No. Mainline Continuing Lanes --> (Input Aux. & Excl. Exit Lanes below)	3	3	3	3	3	3	3	3	3	3	2	2	2	2
Motorway Contol:	Managed													
Grade:	Up to 2%													
HGV %:	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Through Lanes: % of full MSFR	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
MSFR (Through Lanes only)	5775	3975	3975											
MSFR per Through Lane	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1988	1988
Other Adjustments:														
Part. Man. Transition: % of MSFR	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
No. Auxiliary Lanes -->														
Aux. Lanes: % of through MSFR	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
No. Exclusive Exit Lanes -->														
EELs: % of through lane MSFR	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
MSFR (Managed)	5,775	3,975	3,975											
MSFR (Unmanaged)	4,909	4,909	4,909	4,909	4,909	4,909	4,909	4,909	4,909	4,909	4,909	4,909	3,379	3,379

Figure 4-5: Example of Spreadsheet Model for Design Volume / MSFR Route Analysis

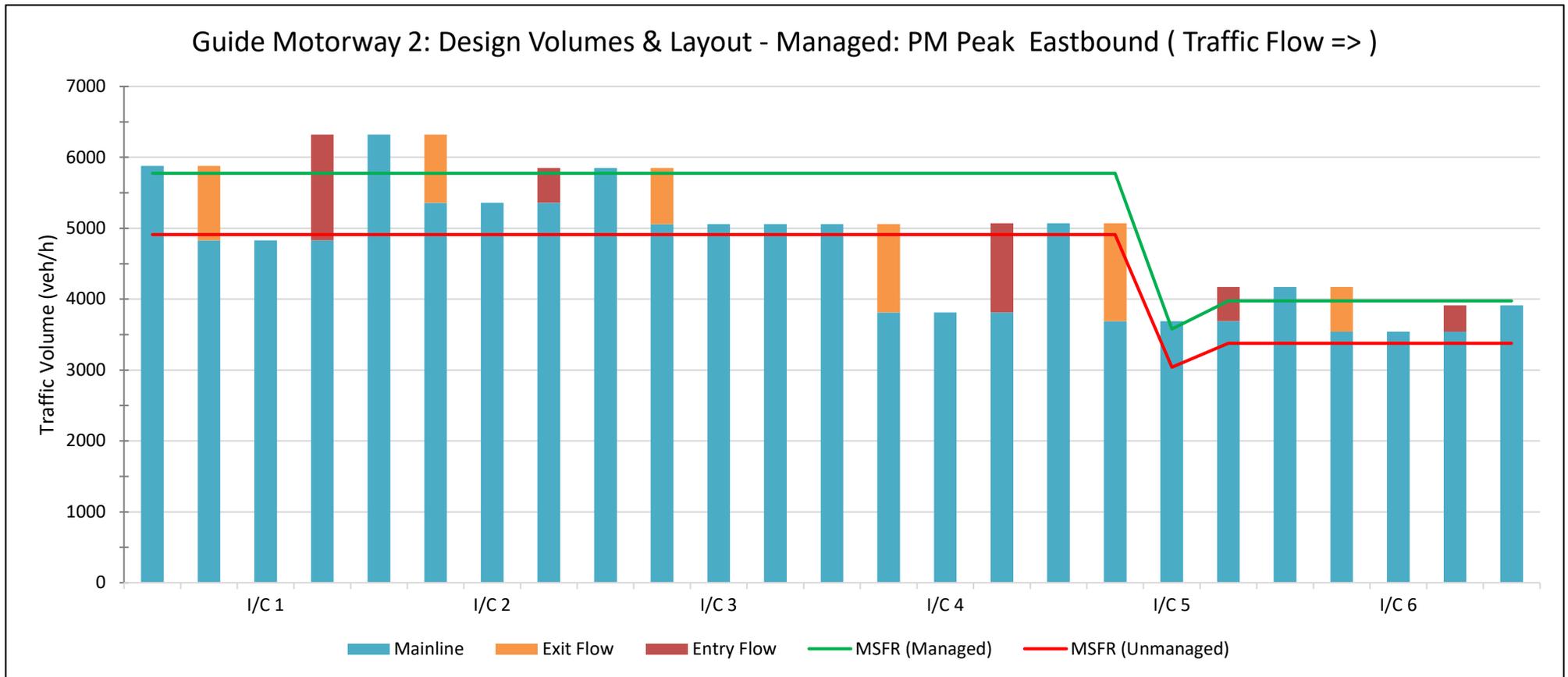


Figure 4-6: Example of Design Volume / MSFR Route Analysis Chart

4.4.5 Partially Managed Transition Zone at the Start of a Ramp Signals System

4.4.5.1 Overview

There is a significant difference between 'fully managed' mainline capacity and 'unmanaged' capacity for motorway segments. Therefore, the mainline segments near to the start of a ramp metering system need a specific analysis focus, as they are deemed 'partially managed' and generally not able to operate at the full level of managed capacity.

The coordinated operation of the ramp metering system requires a number of controlled ramps to develop the full traffic flow benefit. This Partially Managed Transition Zone (PMTZ) shall be assessed as part of the analysis and design to ensure the ramp metering system is able to manage traffic within the full length of the managed motorway project.

In order to manage mainline flow at any specific bottleneck, and hence provide full Managed Motorway capacity, the coordinated system needs to be able to balance demand and equity of access across a number of entry ramps upstream of that motorway segment. Theoretically, the unmanaged demand at any point is calculated by:

- Unmanaged upstream mainline flow entering the controlled section, minus
- Upstream exit ramp flows, plus
- Any upstream flows from uncontrolled entry ramps (including uncontrolled priority lanes), plus
- An estimate of 'minimum flow' from controlled ramps (at maximum cycle time), plus
- Allowing for higher flows to compensate for waiting time or lengthy queues, subject to operational strategies.

4.4.5.2 Concept Level Assessment

The Design Volume/MSFR assessment using partially managed MSFR values within the PMTZ is particularly important if a critical bottleneck is near the start of the managed system. In this case, additional coordinated ramp signals may need to extend upstream within the PMTZ beyond the formal limit of the motorway project.

As a rule-of-thumb, upstream of a critical bottleneck near the start of a managed system, the following number of ramps should be considered for control, subject to the magnitude of flows from each ramp contributing to flow at the bottleneck:

- 6 ramps for a 2 or 3 lane carriageway
- 8 ramps for a 4 lane carriageway
- 10 ramps for a 5 lane carriageway

4.4.5.3 Analysis using Incremental Capacity Increase

For more detailed analysis, a progressive increase in the mainline MSFR transitioning from 'unmanaged' to 'managed' MSFR values shall be assumed at the start of the ramp metering system, i.e. slowly increasing up to the full managed capacity as more ramp meters provide control to manage the mainline. Not checking this aspect of capacity could result in a lack of control after the project is completed as well as under investment in the coordinated ramp signals system.

As part of the Design Volume / MSFR analysis the following principles apply to the PMTZ:

- Unmanaged capacity upstream of the first controlled ramp, i.e. 85% of managed capacity (refer Table 4.1 and Table 4.3).
- 90% of managed MSFR downstream of the first controlled ramp. Typically, a 5% benefit is achieved due to headway management and reduction in merging turbulence.

- A progressive benefit in MSFR for each controlled ramp totalling a further 10% through the remainder of the PMTZ based on the number of carriageway lanes and the rule-of-thumb in Section 4.4.5.2. Typical factors (rounded) are summarised in Table 4.4.

Segment Location	Proportion of Managed MSFR		
	2 or 3 Lanes	4 Lanes	5 or more Lanes
Upstream of 1 st controlled ramp (unmanaged)	85%	85%	85%
Downstream of 1 st controlled ramp	90%	90%	90%
Downstream of 2 nd controlled ramp	92%	91.4%	91.1%
Downstream of 3 rd controlled ramp	94%	92.8%	92.2%
Downstream of 4 th controlled ramp	96%	94.3%	93.3%
Downstream of 5 th controlled ramp	98%	95.7%	94.4%
Downstream of 6 th controlled ramp	100%	97.2%	95.6%
Downstream of 7 th controlled ramp		98.6%	96.7%
Downstream of 8 th controlled ramp		100%	97.8%
Downstream of 9 th controlled ramp			98.9%
Downstream of 10 th controlled ramp			100%

Notes:

1. For PMTZ analyses, ramps with a design hour volume less than 600 veh/h should be ignored, i.e. no progressive increase in capacity for that downstream segment, as low-flow ramps have limited ability to manage demand and build a queue to assist in bottleneck management (due to the 'minimum flow' value within the ramp metering system). However, low-flow ramps still need to be controlled as part of the coordinated system.
2. The consideration of partially managed operations may also need to be considered if the design for the coordinated ramp metering system is inadequate for effective control, e.g. if ramps have inadequate ramp discharge capacity and/or storage and other ramps cannot compensate for the inadequacies (refer Section 6.3.2). This may result in only 85-90% of managed motorway capacity being achieved and sustained.

Table 4.4: Incremental MSFR change within the PMTZ from unmanaged to managed MSFR

As indicated above, coordinated ramp signals within the PMTZ may need to extend upstream beyond the formal limit of a motorway upgrade project.

The analysis example shown in Figure 4-7 shows a 2-lane segment between I/C 6 and I/C 5 that could only be managed after development of the full managed motorway capacity benefit using additional metered ramps in the upstream PMTZ.

If the Design Volume/MSFR analysis (using the PMTZ incremental capacity increase) identifies a ratio for any segment greater than the performance target in Section 4.4.2, then additional controlled ramps upstream of the proposed start of the system should be considered. This can ensure adequate ability to manage demand at the critical bottleneck, and to ensure satisfactory system operation relating to equity of access, sharing of waiting times and balancing of queues.

4.4.6 Uncontrolled Entry Ramps within a Partially Managed System

The difference between 'fully managed' mainline capacity and 'unmanaged' capacity for motorway segments means that the mainline segments downstream of an uncontrolled ramp (i.e. a partially managed system) are not able to operate at the full level of managed capacity.

The capacity of the segment downstream of an uncontrolled ramp shall be considered as 'unmanaged' capacity. If there is coordinated operation downstream of the uncontrolled ramp, a

progressive increase in capacity for the downstream segments shall then be assumed until the full traffic flow benefit and 'fully managed' capacity is achieved. In this case, the evaluation is similar to the principles for analysing the PMTZ provided in Section 4.4.5.

Where an entering motorway-to-motorway ramp is not controlled and relies on separate upstream motorway management which may only be partially effective for the downstream managed motorway, a partially managed MSFR adjustment (generally greater than the 85% unmanaged value) may be appropriate in the analysis.

Designs with uncontrolled ramps (partially managed systems) shall be accompanied by a detailed report outlining the design justification when submitted for approval by VicRoads Road and Traffic Design Department.

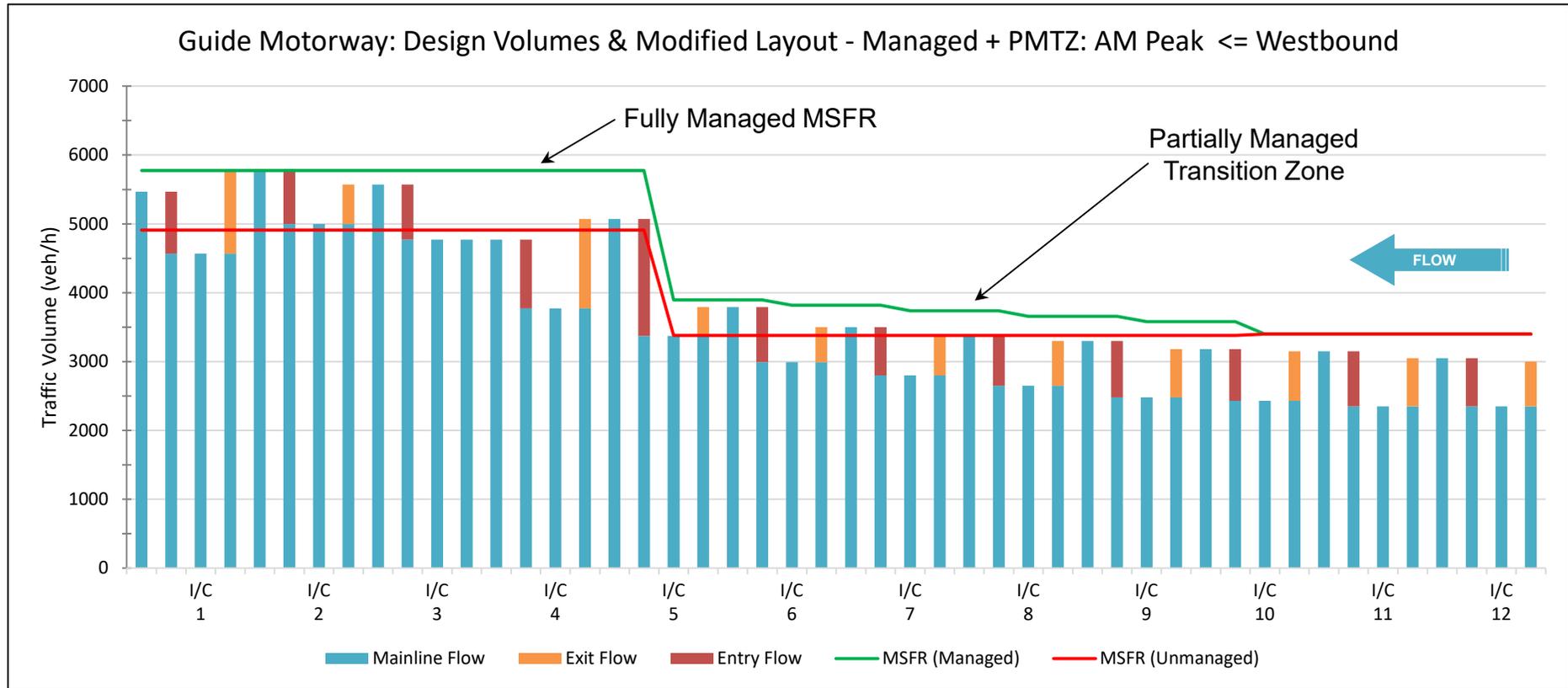


Figure 4-7: Example of Design Volume / MSFR Route Analysis considering the Partially Managed Transition Zone (PMTZ)

4.4.7 Traffic Demand Greater than Mainline Capacity

Where the traffic analysis indicates that the traffic demand (traffic modelling or other design volumes process) along any section of the route cannot be satisfied within the project proposals, this matter impacts the economic evaluation and should be discussed in the project Business Case. This situation may be applicable to the date of opening or at some other date within the nominal project life (minimum 10 years).

The fact that design traffic demand may not be satisfied by the project design is not necessarily considered a fatal flaw as the project constraints are often subject to predefined project scope or budget. A knowledge of what is feasible and achievable in the project context needs to be identified to avoid misunderstandings related to project outcomes. It will also reinforce that to ensure optimum operation of the infrastructure, traffic demand will need to be managed to the capacity of the motorway infrastructure with appropriate operational strategies, e.g. optimum productivity, to minimise flow breakdown etc.

In this situation, traffic demand will need to be controlled with the coordinated ramp signal system, i.e. manage the amount of traffic allowed to enter the motorway according to principles in Volume 1, Part 1: Section 3.5.1 and Part 5: Section 4.4 of the Guide. Entry ramp storage provisions become more critical in this situation and need to be designed accordingly.

Other approaches that could be taken by the project team are to:-

- Carry out an analysis of the rate of traffic growth up to the design year to understand how long the project proposals may operate satisfactorily in the critical bottleneck sections before demand management is necessary, i.e. after what year will forecast flow start to exceed managed capacity.
- Consider what other road improvements could be proposed on the road network to address traffic needs. However, while nominating other projects to alleviate traffic problems may be a means of containing the scope of works for the project being designed, this should not just be seen as an easy solution or excuse to avoid addressing important issues in a design.
- In some cases, as part of the iterative approach, there may be a need to recommend a review of scope for the project being investigated to ensure the project is successful and can be operated and managed effectively after completion. Similarly, a piecemeal approach to only modify a localised area may risk an adverse impact on the system as a whole, with the potential to create another bottleneck problem greater than what the project is endeavouring to address.

Volume 2: Design Practice
Part 3: Motorway Planning and Design

Chapter 5: Design of Mainline Vehicle Detector Locations



5 Design of Mainline Vehicle Detector Locations

5.1 Principles for Detector Locations

Detectors on the motorway mainline provide traffic data for real time flow, speed and occupancy to control the ramp metering signal system as well as for input into the traveller information system, incident management system and historical data for analysis of motorway performance or fine tuning.

The following principles for locating data stations should be applied to urban motorways. On motorways where ramp metering is not provided, the appropriate positioning of data stations, generally as shown in Figure 5-2, can facilitate retrofitting ramp metering at a later date.

Mainline data stations should be installed as outlined below to cover the full length of the motorway (including sections before and after the managed part of the route), with detection of traffic in all lanes at each point.

a) Downstream of Entry Ramps:

- At the end of, or just beyond, the ramp merge taper, generally 320m downstream of the nose for a single lane merge in a 100 km/h section - or greater if a longer distance of acceleration is required (refer Section 6.5.2). This location is generally just beyond the turbulent merging area and a critical mainline site for ramp metering control. This distance also provides appropriate spacing relative to the previous upstream detectors which will typically be about 100m upstream of the ramp nose.
- For entry ramps entering the mainline with a two lane merge (not an added lane), including priority access layouts with two separated merge locations, the mainline detectors would be provided at the end of the first merge (typically approx. 320m from the ramp nose) as well as at the end of the final merge taper.
- In an added lane situation with no merge, the downstream detectors are generally located at a distance of 160m downstream from the physical ramp nose. This location is generally satisfactory in relation to turbulence due to lane changing / weaving manoeuvres of exiting traffic from the mainline at the next downstream exit and entering traffic from the entry ramp moving to an adjacent through lane.

b) Upstream of Entry Ramps:

- Just upstream of the ramp nose with separate detection for the ramp and mainline traffic.

c) Downstream of Exit Ramps:

- Just downstream of the exit ramp nose, with separate detection for ramp and mainline traffic. This is a critical mainline site if there is a reduction in capacity through the interchange between the exit ramp and downstream entry ramp, e.g. a lane drop or exclusive exit lane.

d) Other Mainline Locations:

- Immediately downstream of potential bottleneck locations where traffic flow needs to be managed by measuring the outflows from potentially turbulent areas, e.g. at the end of a lane drop, steep upgrade, tight curve, speed limit reduction or carriageway narrowing, e.g. no shoulder, narrow lanes or a bridge.
- Within potential bottleneck locations (detectors may need to be closer than the typical spacing) and particularly weaving segments, sections with high lane changing, long upgrades or other areas where turbulence would be significant.
- Remaining locations typically at 400m to 500m spacing (i.e. 500m max.) along the full length of the motorway.

Coordination of detection locations with LUMS gantries or other ITS assets should also be considered to facilitate constructability and minimise costs, e.g. for provision of power, communication connections, maintenance, etc. (refer Section 5.4). However, when this is being considered in design it should not compromise adoption of locations required for operational control.

In regard to installation of infra-red vehicle detectors, these are not to be installed across an emergency stopping bay (ESB) where a stopped vehicle could prevent detection of mainline lanes – provision at the entry to an ESB may be advantageous for monitoring vehicles accessing the bay.

5.2 Collector-Distributor Road Detector Locations

Where a CD road is either unmanaged or to be managed with ramp signals, the vehicle detection should be provided according to principles used for mainline detection as outlined in Section 5.1.

Where a CD road enters the mainline it should be considered as a long entry ramp with detection provided according to the principles in Section 6.10.4.

5.3 Detector Locations in Tunnel Segments

For tunnel design and operations it is important to have a high level of control along the mainline to promote and ensure consistent vehicle speed and to minimise the potential for slow moving traffic, flow breakdown and congestion.

In mainline tunnel segments the mainline detection should generally be provided according to guidance in Section 5.1. In view of the desirable management objectives above, the spacing of detection at the lower end of the desirable range is preferred, particularly on long or steep upgrades.

Because both the sag and the tunnel entry portal are critical locations where motorist behaviour is different than at other locations in the tunnel, it will be necessary to have closer spaced vehicle detection at multiple points associated with sags and portals. Detectors generally need to be placed closer together e.g. 300-400m apart covering the downhill, sag and uphill sections as well as outside and inside the tunnel portal, e.g. for a distance of at least 600m inside and outside the tunnel.

5.4 Vehicle Detection and Grouping of ITS Assets

Power supply and communications are required at data station locations and the preferred arrangement is to provide longitudinal conduits for power and optical fibre. Power supply is also needed in the median for infra-red detectors. Alternatively, solar power with adequate and reliable battery back-up can be considered.

Where possible, the location of mainline vehicle detection could be coordinated with other ITS assets, e.g. near a LUMS gantry or CCTV camera location. The grouping of assets near each other generally reduces cost and facilitates constructability and maintenance, particularly in relation to the provision of power and system communications.

Some locations for vehicle detection can be critical to mainline management as indicated above, so compromising locations in order to group assets, including signs, needs careful consideration and will not always be possible for best operational needs.

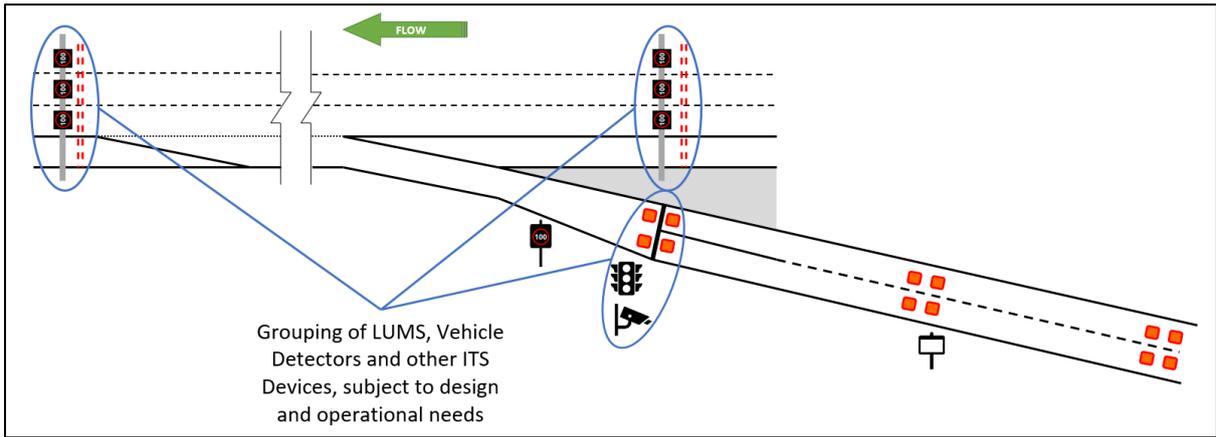


Figure 5-1: Example of Grouping of ITS Assets

Part 3: Motorway Planning and Design

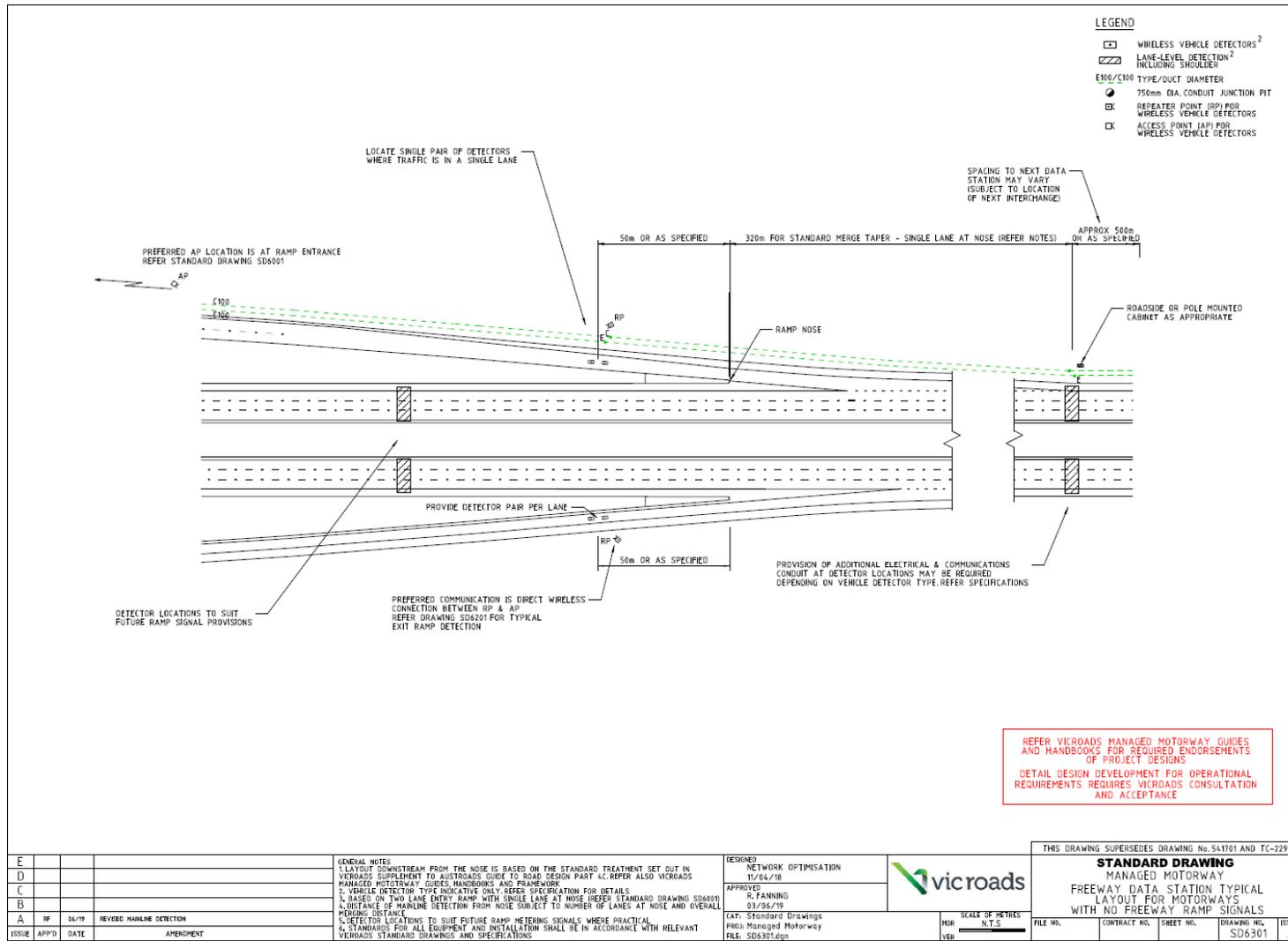


Figure 5-2: Motorway Data Station General Layout

6 Design of Ramp Signals and Entry Ramps

6.1 Overview of the Design Process

The main components of the ramp signal design process at each entry ramp follows an investigation along the motorway to understand motorway mainline design, capacity and performance, including at each ramp entry to the mainline and other potential bottlenecks (refer Chapter 4).

The main components of the ramp metering signals design process is shown in Figure 6-1.

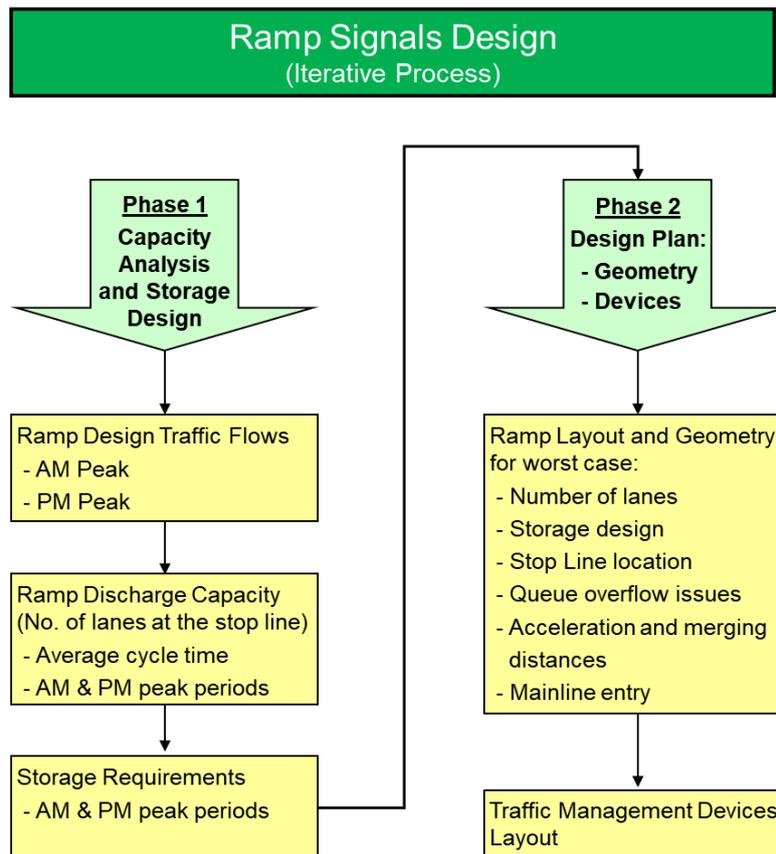


Figure 6-1: Ramp Signals Design Process Overview

It is well known that ramp metering of motorway entry ramps has been used for many years in Melbourne and elsewhere. The VicRoads managed motorway approach (different when compared to most other jurisdictions) is that it applies holistic principles to planning, design and operations, as well as state-of-the-art best practice (traffic theory, principles and analysis) to the traffic management control and algorithms that manage the system.

During operations, the metering rate and storage requirements at an entry ramp will vary at 20 second intervals according to the motorway flow, the entry ramp demand and the operational regime within the system. The objective of the design process is to ensure that adequate consideration is given to the discharge capacity, storage and geometric layout of the ramp (averaged over an hour), so that satisfactory operation is achieved after the ramp signals are installed.

The capacity and storage analyses for all ramps need to be considered for the AM and PM peak periods to determine the worst case, i.e. in some instances the entry ramp flows and desirable storage may be greater in the counter peak direction, even though the mainline flows may be less, e.g. at an entry ramp from a location of significant employment which is in the opposite direction to the peak flow.

It is noted that while capacity analysis in the design process generally focuses on hourly traffic volumes, during operation the dynamic ramp signal system uses occupancy to optimise motorway flow.

For design information not provided in this Guide, designers should refer to the Austroads Guides and VicRoads Supplements, as appropriate.

Background Note: *Historic examples exist where ramp metering signals were installed and subsequently did not meet operational expectations due to inadequate analysis, poor design, and/or misunderstanding of ramp metering principles. Performance problems may involve excessive queuing and delays or other adverse effects on both the ramp and motorway mainline. A good control algorithm may not be able to compensate for an inadequate design.*

6.2 Ramp Discharge Capacity for Design

The ramp discharge capacity is related to the number of lanes at the stop line, the ramp arrival flow, q_{ra} , adopted for design, the number of vehicles per green per lane and an appropriate average design cycle time, c_r , to provide the metering of traffic into the mainline. The average design cycle time can be determined from **Equation 6-1** or the values collated in Table 6.1.

$$c_r = \frac{3600 \times \text{No. lanes at the stop line} \times \text{No. veh/g/l}}{q_{ra}} \quad \text{Equation 6-1}$$

Note: The number of lanes may be assumed and then the resulting cycle time checked relative to the appropriate minimum average cycle time.

On high demand motorways, the desirable minimum cycle time adopted for design and capacity analysis averaged over the design peak hour should typically be not less than:

- 7.5 seconds for ramps merging with the mainline.
- 6.5 seconds for ramps with an added lane, added lane plus merge or two added lanes entering the mainline.

These average cycle time values over the design hour make allowance for real time operational flexibility. Generally, average cycle times lower than desirable minimum cycle times (also shown

orange in Table 6.1), would only be appropriate when the mainline analysis indicates ramp demands are accommodated with spare capacity for several downstream interchanges.

Indicative Layout ⁽⁵⁾	Ramp Design Flow ⁽⁵⁾ (pc/h)	Total Storage Required (Lane-metres)	Ramp Storage ⁽³⁾ and Cycle Time ⁽⁷⁾ Relative to the Number of Lanes at the Stop Line							
			1 Lane		2 Lanes		3 Lanes		4 Lanes	
			Average Storage per Lane (m)	Ave. Cycle Time (s)	Average Storage per Lane (m)	Ave. Cycle Time (s)	Average Storage per Lane (m)	Ave. Cycle Time (s)	Average Storage per Lane (m)	Ave. Cycle Time (s)
Single lane merge ⁽⁶⁾	200	113	113	18.0						
	300	170	170	12.0						
	400	227	227	9.0						
	500	283	283	7.2	142	14.4				
	600	340	340	6.0	170	12.0				
	700	397			198	10.3				
	800	453			227	9.0				
	900	510			255	8.0	170	12.0		
	1,000	567			283	7.2	189	10.8		
	1,100	623			312	6.5	208	9.8		
1,200	680			340	6.0	227	9.0			
Added lane entering the freeway or Two lane merge	1,300	737					246	8.3	184	11.1
	1,400	793					264	7.7	198	10.3
	1,500	850					283	7.2	213	9.6
	1,600	907					302	6.8	227	9.0
	1,700	963					321	6.4	241	8.5
	1,800	1,020					340	6.0	255	8.0
Added lane entering the freeway plus a merging lane	1,900	1,077							269	7.6
	2,000	1,133							283	7.2
	2,100	1,190							298	6.9
	2,200	1,247							312	6.5
	2,300	1,303							326	6.3
	2,400	1,360							340	6.0
	2,500	1,417							354	5.8
	2,600	1,473							368	5.5
	2,700	1,530							383	5.3
	2,800	1,587							397	5.1
2,900	1,643							411	5.0	
3,000	1,700							425	4.8	

Notes:

1. Max wait / vehicle (min.): 4
2. Storage per vehicle (m): 8.5
3. Average storage per lane assumes lanes of equal length. Not applicable with auxiliary lanes at the stop line.
4. No. vehicles/green/lane: 1
5. Ramp layout and design flow are subject to the mainline capacity and mainline / ramp configuration.
6. A single lane merge layout may be satisfactory for higher flows, e.g. a ramp flow of 1400 veh/h entering mainline with adequate capacity.
7. Numbers shown in **Orange** would only be appropriate when the mainline analysis indicates ramp demands are accommodated with spare capacity for several downstream interchanges.

Table 6.1: Discharge Capacity (Stop Line Lanes) and Ramp Storage Requirements

In practice, ramp cycle times may also be influenced by mainline conditions several kilometres downstream and the operation of other coordinated ramps along a motorway corridor. As shown in

Figure 6-2, longer and shorter cycle times (implied by the metering system flow rates) will occur within the dynamic system based on traffic conditions at the bottleneck and coordination relative to other ramps. Recent investigations have also demonstrated that there can be temporal effects (periods of high and lower ramp demand) within the peak hour, e.g. workers leaving an industrial area at about the same time.

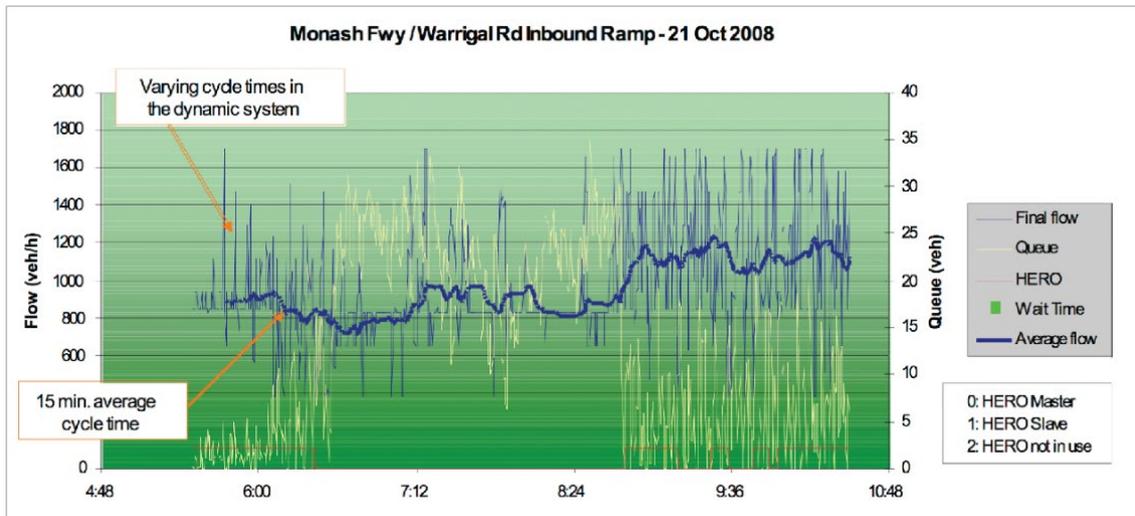


Figure 6-2: Example of Varying and Average Cycle Times Implied by Metering Flow Rates

If a cycle time greater than or equal to the desirable minimum cannot be achieved in design, this will generally result in ineffective metering of ramp demands during operation.

The capacity and operation related to high volume ramps requires particular consideration of the number of lanes and the storage lengths available. In some situations, additional lanes required at the stop line for capacity reasons can be provided by using localised flaring to create a short auxiliary lane, particularly if a long ramp provides adequate storage. Examples are shown in the standard drawings for three and four lane configurations in Section 6.6 and Section 6.7 respectively.

Designs shall be subject to VicRoads approval (Road and Traffic Design Department) where:

- average cycle times less than the desirable minimum cycle time or outside the limits in Table 6.1
- storage provisions less than required in relation to the adopted ramp design flow.

6.2.1 Controlling Very High Ramp Flows

For a ramp with hourly peak design flow in the order of 2,500 veh/h or more, the ramp metering operations may need to consider other non-standard design and operation including:

- Using a double meter, i.e. two stop lines with lateral or longitudinal separation to achieve a total of more than 4 metered lanes. These layouts would require careful consideration of operation when the metering signals are off.
- Metering with more than one vehicle per green per lane (generally undesirable).
- 5 or 6 lane meter.

Options for metering with 2 (or more) vehicles per green per lane have not been fully trialed in Australia, although it is used in some overseas jurisdictions with varying success. It has been used for temporary operations in construction scenarios where no other options are viable and adequate ramp discharge has been needed on a narrowed ramp (e.g. single lane metering arrangement).

While theoretically 2 veh/g/l may seem to provide double the flow compared with 1 veh/g/l, the actual increase is significantly less at low cycle times due to the following:

- Based on overseas experience it is understood that 2 veh/g/l is rarely achieved in practice as driver indecision leads to a lower actual metered rate, typically in the order of 1.7 veh/g/l.
- Generally two seconds longer green time is required with 2 veh/g/l to provide sufficient time for two vehicles to cross the stop line. This leads to longer minimum cycle times.

An example of a two lane ramp with a cycle time of 6 seconds for 1 veh/g/l, compared with 8 seconds for 2 veh/g/l is shown in Table 6.2. VicRoads practice for effective operation and driver compliance is to release a single vehicle per green per lane, even if shorter cycle times need to be adopted.

No. veh/g/lane	1	2	
Green time (sec)	1.3	3.3	
Yellow time (sec)	0.7	0.7	
Red time (sec)	4.0	4.0	
Cycle time (sec)	6.0	8.0	
Flow in 2-lanes (veh/h)	1200	1530	Increased Flow 330veh/h (27.5%)

Table 6.2: Example of Ramp Discharge with Release Rate Greater than 1 veh/g/l

Nevertheless, in exceptional circumstances when 1 veh/g/lane is not workable, e.g. a high flow motorway-to-motorway ramp with 4-lanes at the stop line (say in the order of 2,500 veh/h or more) or where a ramp cannot be widened (e.g. on a structure), then 2 veh/g/lane operation may need to be considered. In these circumstances, until more information is available, a design discharge rate of 1.7 veh/g/lane is appropriate, although storage provisions shall not be reduced below those in Table 6.1 based on the changed discharge rate.

Assuming that these situations will be rare, in some cases it may also be preferable to use longer green periods to manage the ramp traffic similar to a conventional set of signals rather than using 2 (or perhaps 3) veh/g/l. However, although this solution may seem workable, generally in these situations storage is also difficult to achieve due to the high volumes.

Motorway ramp metering designs which use more than 1 veh/g/l or designs that provide stop line layouts not covered in this guide are considered to be a design exception, whether this be for temporary or permanent operations, and shall be subject to approval by VicRoads Road and Traffic Design Department.

6.3 Ramp Storage Analysis and Requirements

6.3.1 Desirable Minimum Standard

The desirable minimum standard is to provide for a total length of storage between the stop line and the ramp entrance to accommodate traffic with a wait time of 4 minutes, i.e. the ramp queue delay. For the purpose of storage design considerations, the ramp entrance is defined as starting clear of the location where pedestrians would cross at the intersection (either marked or unmarked crossing) and excludes the left or right turning lanes leading to the ramp.

This standard shall be provided by lengthening existing ramps when it is economically feasible within design constraints, e.g. no downstream bridge or exit taper. This facilitates operational flexibility to:

- Limit vehicle entry to the motorway when the ramp merge or downstream motorway is at or approaching capacity
- Balance queues and waiting times between adjacent ramps in the coordinated system
- Reduce the likelihood of overflow queues extending onto the surface road
- Provide for short term variations and spikes in traffic demand within the peak period

- Accommodate uncertainties in traffic growth, future forecast volumes or changes in travel patterns, and
- To limit vehicle entry to the motorway during an incident and to facilitate recovery after an incident.

The length of the desirable ramp storage, L_{rDes} is calculated from the number of vehicles in the maximum wait time queue, $n_{rMax-wait}$, the maximum wait time, $t_{Max-wait}$, and the average length of the ramp queue vehicle storage space, L_{vs} as shown in **Equation 6-2**.

$$L_{rDes} = n_{rMax-wait} \times L_{vs} \quad \text{Equation 6-2}$$

where: L_{vs} is typically 8.5 metres or 9 metres with high ramp truck volumes

The number of vehicles in the queue based on the maximum wait time, $n_{rMax-wait}$ is calculated from the ramp arrival (demand) flow, q_{ra} and the maximum wait time, $t_{Max-wait}$ (generally 4 minutes) as shown in **Equation 6-3**.

$$n_{rMax-wait} = \frac{q_{ra} \times t_{Max-wait}}{60} \quad \text{Equation 6-3}$$

Table 6.1 provides a summary of the desirable minimum 4 minutes storage lengths to be provided for various ramp flows. The total storage is shared by the number of lanes along the ramp as shown in the table, or with the total lane length if lanes are of different lengths.

Where feasible the design intent should be to provide more than the desirable minimum 4 minutes storage. Additional storage provides advantages of greater operational flexibility when needed. The ramp storage achieved in the design has implications for the operational management of the motorway (as outlined above), as well as the road network as a whole. Therefore, the storage achieved relative to the desirable minimum guideline shall be documented during scope approval of the project.

As a general principle, storage design should avoid storage on the surface road. If this is proposed, it shall be considered a design exception requiring approval by VicRoads Road and Traffic Design Department (refer Volume 2 Part 1).

When considering designs for retrofitting existing ramps, or for metering of new ramps, it may be necessary to consider lengthening the ramp, e.g. by extending the nose, or by widening the ramp, as part of the iterative design process.

In some cases, storage greater than the desirable minimum may be needed, e.g. if project designs indicate that mainline traffic demand cannot be accommodated by the project design.

6.3.2 Compensating for Storage Design Difficulties

In locations where it is not feasible to provide the desirable minimum storage on an entry ramp, i.e. 4 minute wait time, a lower storage value may need to be considered to facilitate acceptable system operations. Where desirable minimum ramp storage is compromised, it is generally to be expected that the system operation will also be compromised.

Where it is not feasible to provide the desirable minimum storage, a minimum 3 minute queue length may need to be adopted for design as well as consideration of other design options outlined below. Three minute storage will generally be sufficient to accommodate turning vehicles arriving in a platoon from the surface road interchange signals, but is insufficient for assisting with coordination and would restrict the system's ability to build a queue in order to manage mainline traffic and prevent flow breakdown.

Where the desirable minimum standard of storage cannot be provided, alleviating potential operational constraints may be addressed by considering the following:

- Reassessing the chosen ramp layout as part of the iterative design process to adopt a ramp configuration with the Stop Line closer to the ramp nose (e.g. refer 3-lane and 4-lane layouts in Sections 6.6 and 6.7).
- Provide more than the desirable minimum storage at other ramps immediately upstream to compensate for the lack of storage at low storage ramps. This situation is considered a major response requiring analysis and justification. This storage compensation may be particularly important in the Partially Managed Transition Zone (refer Section 4.4.5), as the full traffic flow benefit of managed operation is not yet developed.
- Where storage compensation at other ramps is considered, low volume ramps provide little support in a coordinated system as they are unable to build a queue even with long cycle times. Therefore, low volume ramps, e.g. < 600 veh/h, shall be ignored when evaluating storage to compensate for inadequate storage elsewhere.
- The potential for motorists to change their travel route to other interchanges. For this to be valid, the road network needs to have reasonable capacity and connectivity to provide the opportunity for motorists to change their travel patterns. This may be an option if ramps at adjacent interchanges can be provided with increased storage to accommodate additional traffic or if they already have surplus storage.
- The implications of queue overflow into the surface road and designing the interchange to accommodate this storage in left and/or right turning lanes (refer Section 8.3). Provision of surface road queue detectors in right and/or left turn lanes, as appropriate, would also be required (refer Section 6.10.4.4).

6.3.3 Example of Storage Calculations

The storage calculations along a route can be undertaken in a spreadsheet incorporating the formulas in Section 6.3.1. An example tabulation summarising storage calculations to specify design requirements or for comparing required storage relative to what is provided as part of the iterative design process is shown in Table 6.3.

If there are locations where the desirable minimum storage cannot be provided, the downstream locations of critical bottlenecks shall be considered (refer Table 6.3) with calculation of cumulative upstream storage (refer Section 6.3.2). The example spreadsheet in Table 6.3 includes the downstream Volume/MSFR ratio to assist in identifying critical bottleneck locations and hence to focus on what upstream storage is available.

Part 3: Motorway Planning and Design

Handbook Mwy (Managed): I/C 1 to I/C 6 - Existing Layout / Traffic																				
Ramp Metering Signals Entry Ramp Analysis																				
Eastbound =>																				
4-Apr-18																				
Preliminary assessment																				
Entry Ramp	Ramp Volumes and Control					Ramp Discharge Capacity Analysis		Ramp Storage Analysis								Downstream Segment		Ramp Entry Geometry at Mainline	Comment	
	Proposed Meter (Yes/No)	AM Ramp Flow veh/h	PM Ramp Flow veh/h	Priority Access Lane?	Design Ramp Volume veh/h	Lanes at Stop Line	Average Cycle Time	Distance Stop Line to Ramp Nose (m)	Storage Available						Desirable Minimum (4 min.) Storage (m)	Desirable Additional Storage (m)	Volume / MSFR Ratio (%)			
						Proposed	Proposed		Lane 1	Lane 2	Lane 3	Lane 4	Total	(minutes)			AM Peak			PM Peak
I/C 1	Yes	780	1490	No	1490	3	7.2		40	380	380			800	3.8	844	44	76%	109%	Added Lane + Merge
I/C 2	Yes	1050	490	No	1050	2	6.9			310	310			620	4.2	595	ok	91%	101%	Merge
I/C 3	No Ramp	0	0	No	0		--							0	-	-	-	86%	88%	n.a.
I/C 4	Yes	670	1260	No	1260	3	8.6		40	390	390			820	4.6	714	ok	83%	88%	Merge
I/C 5	Yes	330	480	No	480	2	15.0			250	250			500	7.4	272	ok	102%	105%	Merge
I/C 6	Yes	210	370	No	370	2	19.5			240	240			480	9.2	210	ok	94%	98%	Merge

Handbook Mwy (Managed): I/C 1 to I/C 6 - Existing Layout / Traffic																				
Ramp Metering Signals Entry Ramp Analysis																				
<= Westbound																				
4-Apr-18																				
Preliminary assessment																				
Entry Ramp	Ramp Volumes and Control					Ramp Discharge Capacity Analysis		Ramp Storage Analysis								Downstream Segment		Ramp Entry Geometry at Mainline	Comment	
	Proposed Meter (Yes/No)	AM Ramp Flow veh/h	PM Ramp Flow veh/h	Priority Access Lane?	Design Ramp Volume veh/h	Lanes at Stop Line	Average Cycle Time	Distance Stop Line to Ramp Nose (m)	Storage Available						Desirable Minimum (4 min.) Storage (m)	Desirable Additional Storage (m)	Volume / MSFR Ratio (%)			
						Proposed	Proposed		Lane 1	Lane 2	Lane 3	Lane 4	Total	(minutes)			AM Peak			PM Peak
I/C 6	Yes	800	500	No	800	2	9.0			190	170			360	3.2	453	93	95%	79%	Merge
I/C 5	Yes	1700	1200	No	1700	3	6.4		40	430	410			880	3.7	963	83	88%	69%	Add Lane
I/C 4	Yes	1000	1200	No	1200	3	9.0			300	320			620	3.6	680	60	83%	80%	Merge
I/C 3	Yes	800	500	No	800	2	9.0			250	250			500	4.4	453	ok	96%	88%	Merge
I/C 2	Yes	1000	200	No	1000	2	7.2			250	250			500	3.5	567	67	104%	75%	Merge
I/C 1	Yes	900	700	No	900	2	8.0			220	220			440	3.5	510	70	98%	71%	Merge

Table 6.3: Examples of Ramp Storage Calculations

6.4 Geometric Design and Layout of Entry Ramps

6.4.1 General Ramp Configuration

The general layout of motorway ramp metering signals at various entry ramp configurations are shown on the Standard Drawings outlined in Section 6.4.4, with the choice of the mainline / entry ramp layout generally as provided in Section 4.3.2.12 to ensure mainline capacity and minimise turbulence.

The layouts in the standard drawings are based on the geometric standards for freeway entry ramps in VicRoads supplement to the Austroads Guide to Road Design: Part 4C – Interchanges (VicRoads, 2010). This is to ensure that the ramp geometry and merging distances are satisfactory when the metering signals are operating as well as when the signals are not operating.

When retrofitting an existing entry ramp with ramp signals, the length available for acceleration and merging shall be checked to ensure the overall design is satisfactory and meets current design standards. The general design process should include site investigation to be aware of matters that could affect the feasibility of upgrading proposals.

The discharge capacity (number of lanes to be provided at the stop line) and the desirable minimum storage length for vehicles need to be provided based on analyses described in Sections 6.2 and 6.3. Ramp designs for discharge capacity and storage are necessary for system-wide operation and optimisation.

6.4.2 Motorways with Tunnel Sections

Minimising lane changing increases the inherent safety of a tunnel. Entry ramps that require merging and lane changing are undesirable within the tunnel or close to the tunnel portal.

The merging manoeuvre requires that drivers of all vehicles (mainline and ramp traffic) adjust their speed and location to facilitate the lane changing. Minimising merging and lane changing in a tunnel helps to maintain consistent vehicle speeds and therefore improves safety and reduces turbulence. The management of ramp and mainline traffic, including the merges and downstream sections of motorway, provides one of the most effective means of mitigating impacts on tunnel safety and operational performance.

Entry ramps and merges in the proximity of a tunnel may create a risk to tunnel traffic where the traffic is merging. Preferably the end of the merge taper should finish not less than 500m prior to the tunnel portal. This also ensures that the ramp metering signals on the ramp are located well before the tunnel portal.

Where network connections and other physical constraints require ramps and merges in close proximity (i.e. closer than 500m), or within, tunnel sections, guidance and direction shall be sought from VicRoads subject matter experts or VicRoads' nominated representatives. In such circumstances, the location of ramps and merges and the associated geometric arrangements and technology provisions require approval by VicRoads Road and Traffic Design Department.

Any entry ramps and merges in the proximity of the tunnel portal or within the tunnel environment shall be considered as high risk, as poor design of these interfaces can contribute to dangerous behaviour of drivers and a resulting increase in the risk level and incidents.

Design of tunnel and ramp interfaces shall include input from Human Factors specialists with expertise in road tunnel environments to minimise the possibility of late and unexpected actions from drivers near the access points.

Specific treatment options will depend on context (i.e. including approach geometry), but could include unique designs at each access location to assist drivers with orientation and required behaviour at high risk areas. Generally best international practice has considered inclusion of some or

all of appropriate illumination, patterns, colour, architectural installations treatments etc. where considered necessary (PIARC Technical Committee 3.3 Road Tunnel Operation, 2016).

Design solutions shall consider best international practice and are required to address risk and context at each access interface with risk mitigation proposals, analysis and decision making clearly documented in associated Design Reports.

6.4.3 Stop Line Location

The positioning of the stop line needs to achieve a balance between safety for merging traffic and maximising ramp storage. As a general principle, the stop line distance from the nose should be as indicated on the Standard Drawings and these guidelines so that the storage is maximised, even if the ramp is longer than the calculated desirable minimum distance. This maximising of storage provides greater flexibility in operation when traffic demands are high and/or the mainline flow conditions warrant a higher level of management.

The stop line location relative to the ramp nose varies for the two, three and four lane ramp configurations as outlined in the following sections. As general design principles:

- The merging of traffic leaving the stop line is completed by the ramp nose to match the entry arrangement onto the mainline and provide adequate time for drivers to assess their subsequent mainline merge manoeuvre. Separated decision making points are provided where multiple merge manoeuvres are required between stop line and nose.
- The shoulder width is fully developed adjacent to the nose. This acts as a ‘run-out’ area and provides additional width for safety in the event that merging manoeuvres are not completed by the nose.

In situations where increased storage is needed, consideration may need to be given to extending the ramp nose and the overall acceleration and merge taper length(s) to maintain the desirable standards.

6.4.4 Standard Drawings

The general layout of motorway ramp metering signals at various entry ramp configurations are shown on the standard drawings listed in Table 6.4 with further details provided in Sections 6.5 to 6.8.

The choice of treatment is based on the mainline / entry ramp configuration (refer Section 4.3.2.12), the ramp discharge capacity (refer Section 6.2) and storage considerations (refer Section 6.3).

Ramp Type	Drawing No.
Two lanes of metered traffic	SD6001
Two lanes of metered traffic plus a metered priority lane – Option P1	SD6002
Two lanes of metered traffic plus a metered priority lane – Option P2	SD6003
Three lanes of metered traffic	SD6101
Four lanes of metered traffic	SD6102
Exit ramp management system	SD6201
Freeway data station typical layout	SD6301
Motorway-to-motorway interchange – FRS infrastructure locations	SD6401

Note: Refer VicRoads website for latest versions and for electronic copies of the drawings for printing in A3 size

Table 6.4 Standard Drawings for Motorway Ramp Signals

6.5 Two Lane Metered Entry Ramp

6.5.1 Typical Layout

The typical entry ramp layout for a ramp with two metered lanes is shown in Figure 6-5. For this layout the stop line is generally located a minimum of 80 metres upstream of the ramp nose which aims to maximise ramp storage while still providing safe operation for acceleration and merging when the ramp metering is on, as well as when the signals are off (refer geometric design principles in Section 6.5.2).

The distance of 80 meters upstream of the ramp nose should also be adopted on long ramps as this provides consistency between similar ramps and maximises ramp storage to provide operational flexibility for system effectiveness.

A similar layout would be adopted for ramps only requiring a single lane for ramp discharge capacity (refer Table 6.1), however, it would also be desirable to design these ramps to facilitate easy retrofitting to 2-lane operation. Using a 2-lane layout for low flow ramps can facilitate provision of storage so should also be considered for low flow ramps.

6.5.2 Geometric Design Principles

When the Ramp Signals are Turned On

Operational safety needs to be provided when the ramp signals are operating as shown in Figure 6-3. The ramp entry dimensions shown in Figure 6-3 are based on ramp geometry typically adopted in 100km/h speed limit environments. Distance considerations for safe operations include:

- Acceleration from a stationary position at the stop line during metering operations.
- Acceleration to a mainline merging speed of 80 km/h relative to a left lane mainline operating speed of 90 km/h, i.e. a 10 km/h speed differential (refer Figure 6-4 and associated note below). Studies have shown that an operating speed of 90 km/h is appropriate during periods of high flow when the ramp meters switch on.

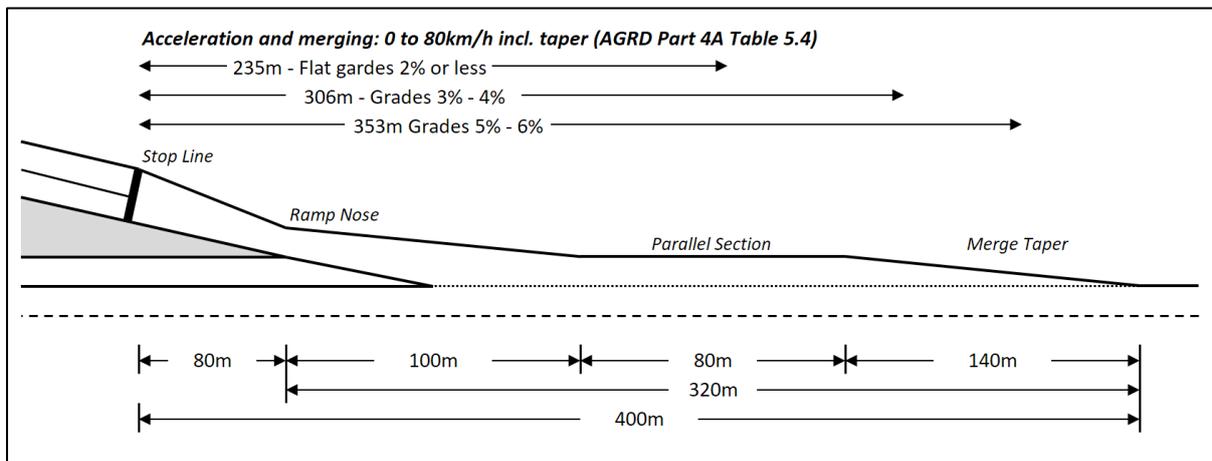


Figure 6-3: Illustration of Typical Acceleration Distances Relative to Single Lane Ramp Merge Geometry



Note: Also refer Volume 1, Part 2: Section 4.3

Note: On a 4-lane motorway in an urban motorway environment there can be a 20km/h differential between the slow and fast lane, i.e. 5-7km/h speed differential occurring between adjacent lanes (refer to Volume 1, Part 2). In this example, when the motorway is operating near its highest productivity (based on achieving low risk of breakdown and high level of reliability), the average carriageway speed is about 87km/h.

Figure 6-4: Typical lane speed differentials on a 100 km/h four-lane urban motorway

When the Ramp Signals are Turned Off

Operational safety needs to be provided when the ramp signals are not operating. This includes:

- Merging within the ramp (at speed) from the number of lanes at the stop line to a lesser number of lanes at the ramp nose. This assumes:
 - Design speed on the ramp for merging: 80 km/h
 - Merging manoeuvre based on lateral movement at 1.0 m/s (acceleration lane merge for 2-lane and 3-lane layouts)
 - Required merging manoeuvres to be completed prior to the ramp nose

Other Provisions or Matters to Consider:

- **Design for trucks.** The standard layout has been satisfactory for trucks based on the operation of current ramp metering signals installed. Nevertheless, on ramps with high truck volumes a greater merging distance could be considered as indicated below.
 - The Austroads Guide to Road Design Part 4A (Section 5.5) indicates that: 'As trucks require very long acceleration distances, often to an extent that it is not possible to accommodate in practice, a speed differential between general traffic and heavy vehicles will usually have to be accepted at the point of merging.'
 - For projects which may be specifically focussed on freight improvement, this will be addressed by overall Managed Motorway benefits including improved capacity, travel time and reliability.
- **Shoulder.** At the ramp nose the shoulder shall be fully developed as a run-out area.
- **Speed limit signs.** Mainline entry speed limit signs are located after leaving the stop line, typically 20 metres upstream of the nose.

The stop line distance from the nose and/or the length of the ramp may need to be increased for site specific conditions such as:

- Where the merge area is on a steep upgrade, particularly on grades over 5% where otherwise the acceleration distance includes part of the final merge taper (refer Figure 6-3).

- To improve the visibility to the signals due to a crest, curve, vegetation or other restriction.
- Where a curved ramp alignment restricts sight distance to the two-to-one lane merge area.
- Where the ramp traffic includes a significant number of trucks (such as significant freight access locations), particularly ramps or merging areas on upgrades, or
- On long high standard ramps that may operate at high speeds.

Alternatively, where the merge area is on a steep grade and/or there are a significant number of trucks, the merge distance on the motorway itself could be increased, particularly when this can be achieved without compromising entry ramp storage.

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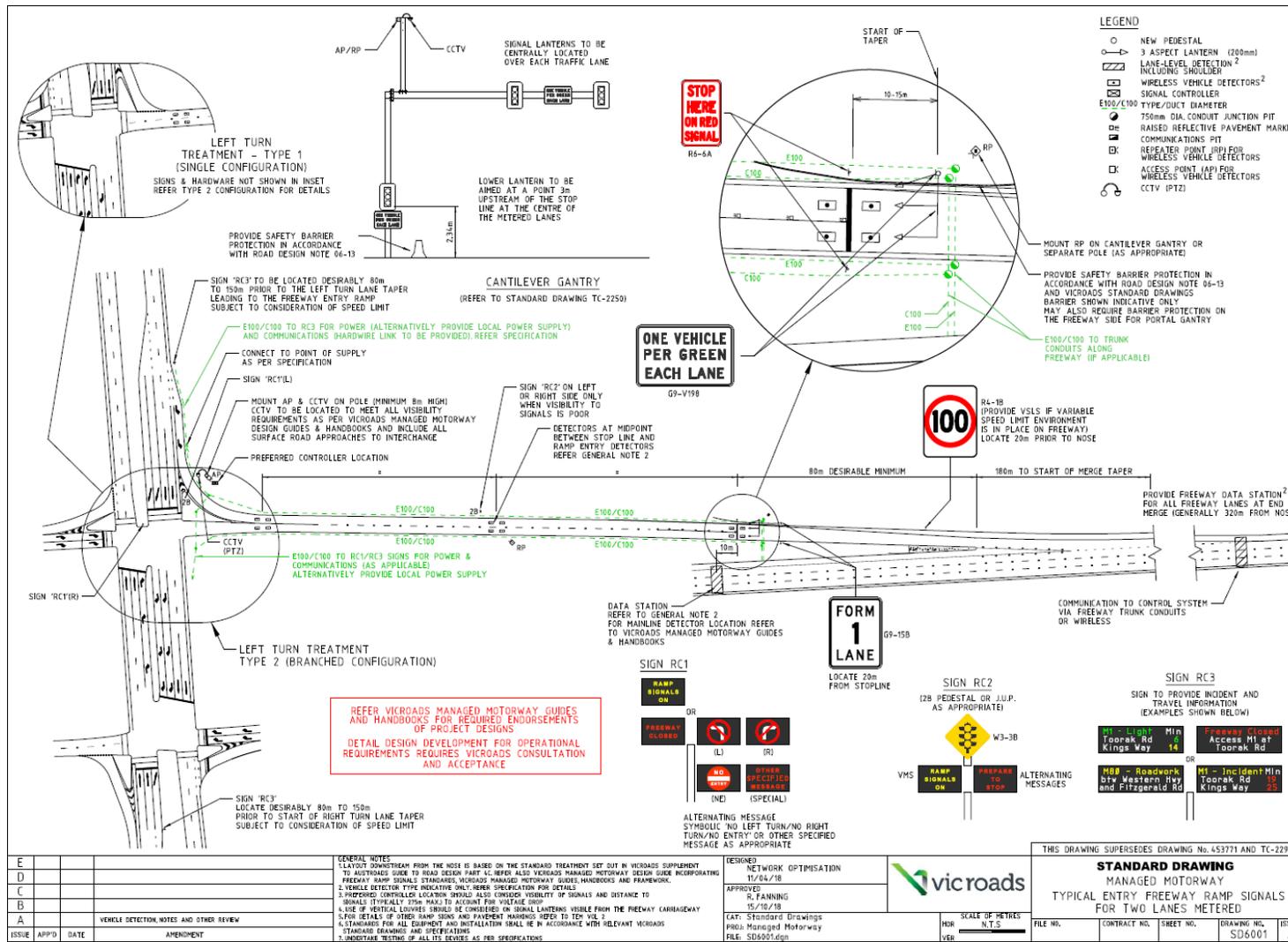


Figure 6-5: Typical Motorway Ramp Metering Signals Layout - 2 Metered Lanes

6.6 Three Lane Metered Ramps

The typical entry layouts for ramps with three metered lanes at the stop line are shown in Figure 6-7. An example of 3-lane and 4-lane ramp metering signals on a CD road entering the mainline is also shown in Figure 6-6.

If two lanes are provided at the nose, i.e. two lanes added to the motorway mainline or a single lane merge plus an added lane, the merge distance for vehicles leaving the stop line is similar to the two lane layout. This layout for higher volume ramps generally enables storage to be maximised.

For other ramp layouts with three lanes at the stop line, greater distances between the stop line and the nose for the merging movements are required, particularly if three continuous lanes on the ramp need to merge into a single lane at the nose. For the three to one lane merge, the distance also varies according to whether the third lane along the ramp is continuous (full time use) or a short auxiliary lane at the stop line (part time use when the signals are on).

A staggered stop line layout with an auxiliary lane can be considered as outlined in Appendix D (Extended Design Domain), where the desirable minimum storage is not achievable with a standard layout.

6.7 Four Lane Metered Ramps

The typical entry layouts for ramps with four metered lanes at the stop line are shown in Figure 6-8. The metering layouts with four lanes at the stop line require a minimum distance of 120m between the stop line and the ramp nose (based on a lateral movement at 0.6 m/s and allowing for human factors associated with multiple vehicles merging consecutively). This distance is desirable in view of the complexity of the decision making involved with a larger number of vehicles being released at the same time.



Aerial Photo Source: Google

Figure 6-6: Examples of 3-lane and 4-lane Ramp Metering Signals Layouts from CD roads

Figure 6-8 (Standard Drawing SD6102) shows various stop line and merge configurations for four-lane metering layouts. The main variation between the configurations is the merge arrangements and the resulting distance from the stop line to the nose. Layouts 4-1 and 4-3 merge two lanes in parallel over 120m while Layout 4-2 merges the three left lanes (the leftmost lane being locally flared) over 150m, retaining a dedicated lane for the remaining lane. Layout 4-2 is better suited to locations where the rightmost entry ramp lane merges with a carriageway that is likely to have high flows in the left mainline lane. Merging three lanes to one to then feeding an added lane to the motorway can provide better balance of flows downstream of the ramp entry. It needs to be noted that the additional merge length in Layout 4-2 results in less storage than the alternatives.

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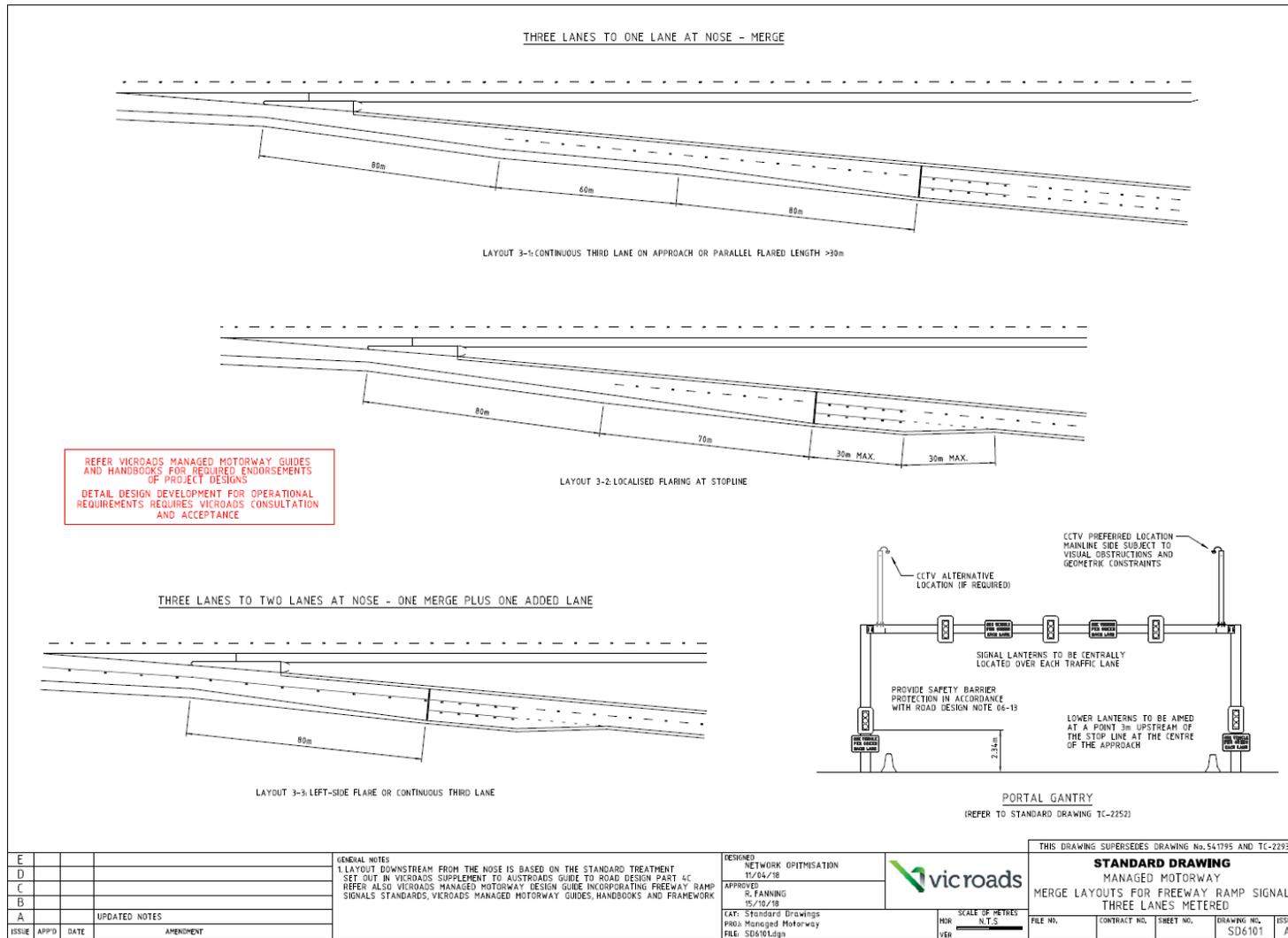


Figure 6-7: Typical Motorway Ramp Metering Signals Layout - 3 Metered Lanes

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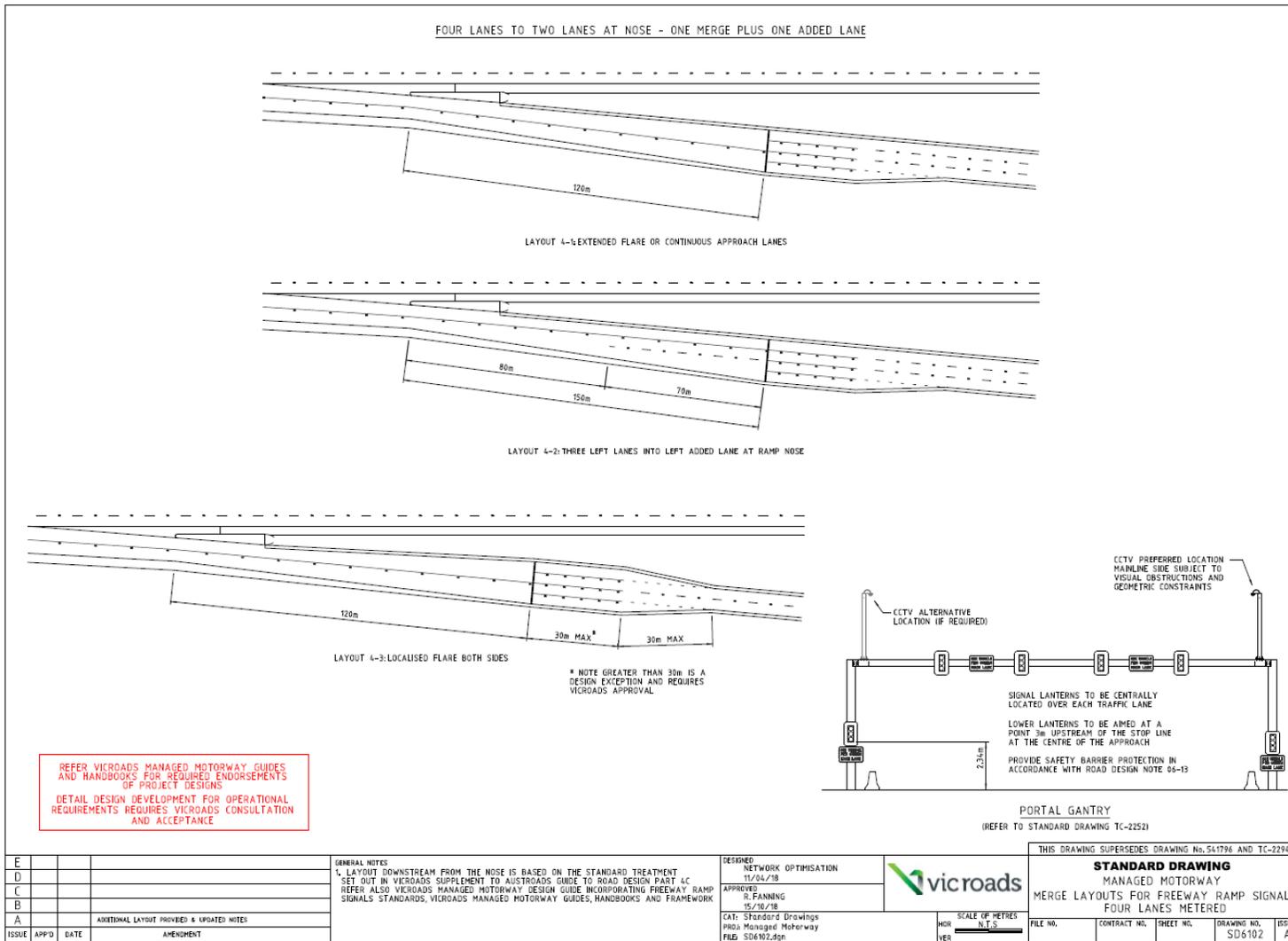


Figure 6-8: Typical Motorway Ramp Metering Signals Layout – 4 Metered Lanes

6.8 Priority Access Lanes

6.8.1 Context and Rationale

To provide an access advantage to selected vehicles, an additional entry ramp lane may be installed to give priority to those vehicles relative to the general traffic ramp queue. Selection and configuration of treatments incorporating priority access lanes for inclusion in motorway projects requires approval by VicRoads Road and Traffic Design Department.

As a Managed Motorway needs control of all inflows, the priority vehicles shall always be metered into the motorway to ensure the mainline is properly managed for best overall outcomes. With an uncontrolled priority lane, the traffic volume and bunching that can occur increases the potential for triggering unstable operation and flow breakdown. The metered priority lane still provides a high level of priority as the queue in the priority lane is significantly shorter and hence priority vehicles have the advantage of lower delay before entering the motorway. Free-flow bypass configurations are no longer provided on new ramp metering facilities and upgrades of previously installed free-flow facilities require modification to provide metered priority access arrangements as part of project improvement works.

A metered priority access lane may be provided to improve the service level for:

- Trucks – in recognition of the economic value of efficient movement of freight or to allow heavy vehicles to reach motorway operational speeds on uphill grades
- Public transport priority where the entry ramp is part of a public bus route.
- Vehicles occupied by more than one person as an incentive for people to share vehicles. However, care is required that the forecast volumes of high occupancy vehicles allowed to use a priority lane does not undesirably impede other priority vehicles and negate the project objective sought through priority lane provisions.

With appropriate regulatory signing as outlined in Section 6.10.9, a priority lane is enforceable under Road Safety Road Rules (Victorian Legislation and Parliamentary Documents, 2009) (Rules 154, 156, 157 and 158).

Where a motorway is managed to optimise traffic flow, maximum utilisation of the mainline infrastructure is provided to keep all lanes operating efficiently and to reduce overall trip times. Therefore, when compared with the use of a dedicated priority lane on the mainline that is generally underutilised (as well as other effects as outlined in Section 4.3.2.11), the use of priority access lanes on an entry ramp, in association with motorway entry ramp signals to manage flow on the mainline for all vehicles, is the most effective option for maximising the productive use of the motorway.

Given the importance of ramp capacity and storage, priority access lanes shall only be provided where there is a significant strategic need and demonstrated demand and provision of the additional lane does not compromise the width, number of traffic lanes and storage required for general traffic.

Guidance for situations where priority access lanes may need to be considered includes:

- Sites where a bus route uses the ramp
- Ramps on critical parts of the Principal Freight Network (PFN)
- Other ramps not on the PFN but with high truck volumes
- In response to policy to encourage car occupancy greater than one person. This would usually be applicable to high volume ramps where the proportion of high occupancy vehicles could justify a separate lane. The Transit Lane benefit is more often a fringe benefit where the priority access is provided primarily for trucks or public transport.
- Where analysis indicates a marginal need for another metered lane on the ramp, i.e. a better alternative may be to provide a priority access lane rather than an extra metered lane.

Two options are outlined below for providing dedicated priority lanes on metered entry ramps up to the metering stop line.

An additional “Queue Jump” configuration may be considered that provides the ability for priority vehicles (generally buses) to bypass a significant length of queued ramp traffic without a dedicated lane at the metering stop line. Where a ramp metering configuration incorporates a flared stop line arrangement (refer to Figure 6-7 and Figure 6-8), priority vehicles may be permitted to utilise the left shoulder of appropriate width on the ramp in advance of the flare and join the shorter queue of traffic. Appropriate signage should be installed to support the use of the shoulder by a priority vehicle when ramp metering is operating.

6.8.2 Metered Priority Lane: Option P1

The priority lane layout shown in Figure 6-9 has the advantage of a long acceleration and merging distance which enables the stop line to be located 80m from the ramp nose (similar to a normal 2-lane metered layout), i.e. maximises the availability of storage on the ramp. However, this generally involves more extensive roadworks and cost when compared to the Option P2 layout.

The Option P1 ramp layout also incorporates the following design principles:

- Separation line marking (generally 0.7m wide) is provided between the priority lane and the metered vehicle lanes. This separation tapers to a single line over the 80m merge distance beyond the stop line.
- The distance of 180m from the nose to the start of the priority lane merge taper is consistent with the standard merge length from the nose to the start of the merge taper. This distance allows vehicles to merge with the motorway traffic or choose to stay in the auxiliary lane and allow priority vehicles to merge.
- The 140m priority lane merge taper is the standard motorway merge length. The shoulder is developed over this distance.
- The 100m parallel auxiliary lane is based on 4 seconds travel at 100km/h. Where downstream obstructions restrict the available length, this parallel section may be reduced.
- The 140m final merge taper is the standard motorway merge length.
- Kerb and channel is generally provided over the total distance of 560m available for the merging movements downstream of the ramp nose.

6.8.3 Metered Priority Lane: Option P2

Option P2, an alternative for locations with restricted ramp lengths and/or right of way, is discussed in Appendix A.

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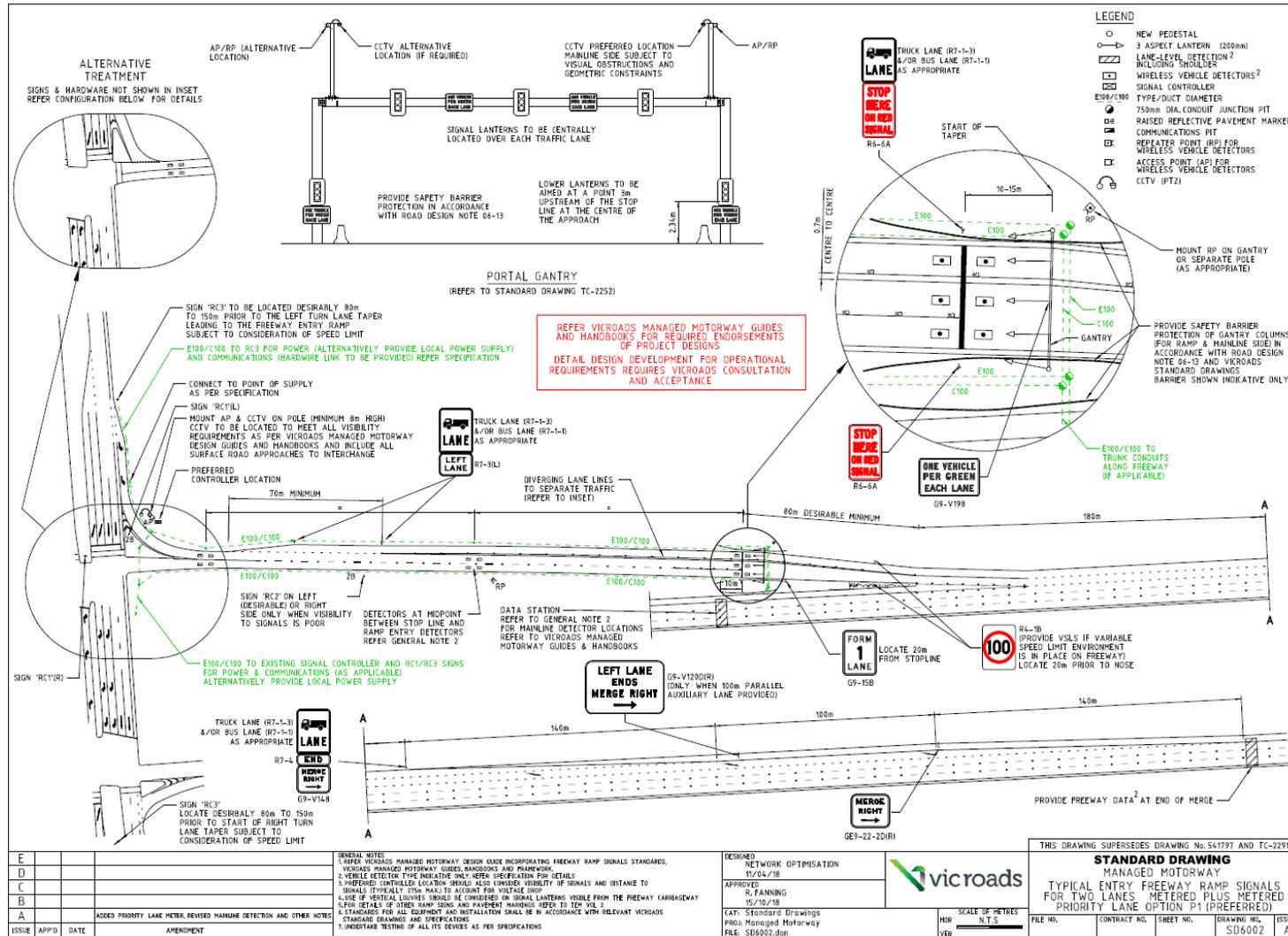


Figure 6-9: Typical Layout - Metered Priority Lane: Option P1

6.9 Designing for Future Retrofitting Ramp Signals

In the design of new motorways or ramps that do not meet the criteria for the provision of ramp signals within the 10 year timeframe, it is desirable to incorporate future provision for ramp signals that are likely to be retrofitted. This would generally be incorporated in outer urban or urban growth areas as well as on inter-urban motorways connecting to regional cities. Refer to Volume 2 Part 1.

The specific design features that should be considered to facilitate the future retrofitting of ramp signals are:

- The ramp width between the ramp entrance and the future stop line location should provide for the minimum width likely if the ramp was to be metered. This is typically a minimum of two lanes (minimum 7.0m and allowance for barrier clearances where required) with interim marking of a single lane and shoulder
- For ramps with potential for higher entry flows consideration of future ramp widening / lengthening to suit three or four lane layouts
- The provision of full depth pavement under shoulders to provide for future traffic when an additional lane is marked to avoid costly pavement modification
- Entry ramp lengths (minimum 420 m from ramp entrance to physical nose) to provide for future storage (up to 1,200 veh/h)
- Location of conduits along ramps. In some instances it would be desirable to install power and communications conduits as part of the initial ramp construction, particularly if other conduits are being installed, e.g. for roadway lighting or motorway data stations
- The provision of data stations at interchanges for traffic counting and evaluation of future traffic management needs with detector locations designed to suit ramp signals
- The position and spacing of drainage pits, including consideration of flow width if a shoulder is converted to a traffic lane.

6.10 Layout of Ramp Signal Devices and Traffic Management

6.10.1 Controller Location

The controller should be positioned in a safe location for workers at the cabinet with nearby space for vehicle access and parking. A reasonably flat area (minimum 1900 x 1200) is required for the foundation and paving at the access doors. Access to both sides of the cabinet is required. A location to facilitate connections to power and system communications is necessary. Generally, visibility of the signal lanterns from near the controller is desirable.

A controller location near the ramp entrance provides benefits for worker safety and access. This location also facilitates radio communications, if provided, to ramp control signs on the surface road, as well as being relatively close for viewing of the ramp control signs. This location is also convenient for providing a pole near the surface road to be used for a CCTV camera and/or a wireless detector access point (refer Sections 6.10.11 and 6.10.4 respectively).

An alternative location for the controller is on the left side of the ramp between the traffic signals and the stop line. In this location the signals are visible and the controller is protected behind the guard fence which shields the signal pedestal. Installation near the signals may be difficult due to the available width adjacent to the ramp or the proximity of cut or fill slopes. In some instances the controller may need to be installed part way along the ramp. A controller location between the ramp and the motorway carriageway is generally undesirable.

6.10.2 Signal Pedestals

The signal support pedestal is installed adjacent to the ramp 10-15m metres downstream of the stop line. The use of a cantilever support structure (Standard Drawing No. TC-2250) is the preferred and usual standard for 2 lane ramps. The use of a pole extension facilitates fixing of detector and CCTV devices (Standard Drawing Nos. TC-2221 and TC-2222).

The use of 2B pedestals each side of the ramp have also been used successfully and may be considered at sites where a cantilever structure is inappropriate, e.g. due to a height or visibility restriction. Alternatively the use of a 2B pedestal with a joint use pole (JUP) for installation of detector or CCTV equipment may be considered.

Gantries are provided for ramps with 3 or 4 lanes. Where overhead lanterns are provided on a cantilever or gantry, the clearance to the underside of the lowest fixture on the structure shall be 5.4m, or 5.9m on an over dimensional (OD) route, in accordance with the VicRoads road design guidelines.

As the traffic signal pedestal (cantilever, JUP, 2B or gantry) is considered a non-frangible roadside hazard, the installation would generally include a safety barrier, typically guard fence. This barrier also serves to protect the signal controller, if it is installed at this location. An advantage of using a cantilever structure is that it only requires guard fence on one side of the ramp. Where a pole needs to be located on the motorway side of the ramp, consideration shall also be given to provision of safety barrier(s) on the side adjacent to the main carriageway.

6.10.3 Signal Lanterns

Standard 200mm three-aspect LED lanterns are used for ramp signals. These are provided as high mounted lanterns with good visibility for approaching motorists and as low mounted lanterns for releasing vehicles at the stop line.

The high mounted lanterns are to be aimed towards the ramp entrance or to maximise sight distance, e.g. where there is a curved ramp. Subject to the length of the cantilever or gantry used, lanterns would be provided overhead on a structure as indicated on the standard drawings.

The positioning of the overhead signals is to mount the lanterns directly over the centre of the lane (refer standard drawings).

On a cantilever or gantry, the low mounted lanterns shall be provided and are to be installed at a height of 2.34m (approx. 2.2m to the underside of the target board). On a gantry arrangement, with 3 or more lanes, low mounted lanterns must be provided on both sides. The lower lanterns are to be aimed at a point at the centre of the ramp approach 3m upstream of the stop line to maximise visibility to the signals for drivers waiting at the stop line.

Where a JUP and/or a 2B pedestal are used instead of a cantilever, they are to be provided on both sides of the ramp, with two lanterns on each pedestal. The lower lanterns are to be mounted at a height of 1.2m (to bottom of the lowest aspect) with the One Vehicle Per Green Each Lane (G9-V198) signs installed between the high mounted and low mounted lanterns. The upper lanterns shall be installed in the high mount position (2.92m high). The low mounted lanterns are to be angled towards a point 3m upstream of the metering stop line in the centre of the ramp. The upper lanterns are to be angled further up the ramp for approaching traffic to suit the approaching ramp geometry.

6.10.4 Entry Ramp Vehicle Detectors

6.10.4.1 Stop Line Detectors

The detectors immediately upstream and downstream of the stop line within each lane perform different functions. The detectors upstream of the stop line (leading detectors) are provided to detect the presence of a vehicle and actuate the green signal. When the upstream detectors are unoccupied

the signals are held on red. This prevents the signals cycling when there are no waiting vehicles and helps to avoid driver confusion in relation to timing their arrival and deciding whether to stop or not.

The detectors downstream of the stop line (trailing detectors) are provided for general traffic counting data as well as vehicle counting associated with the metering control algorithm and ramp queue length estimates.

Provision of stop line detectors, both upstream and downstream, applies to all lanes under all ramp configurations and stop line layouts, including metered priority lanes and staggered stop line layouts.

6.10.4.2 Middle of Ramp Queue Detectors

The middle of ramp detectors are used for queue length estimates and queue management.

The detectors are provided at the midpoint between the stop line and the ramp entrance when ramp lanes are of similar length. Where a ramp has unequal length of storage lanes, the detectors are located at the middle of the overall storage length, i.e. not the middle of the physical length.

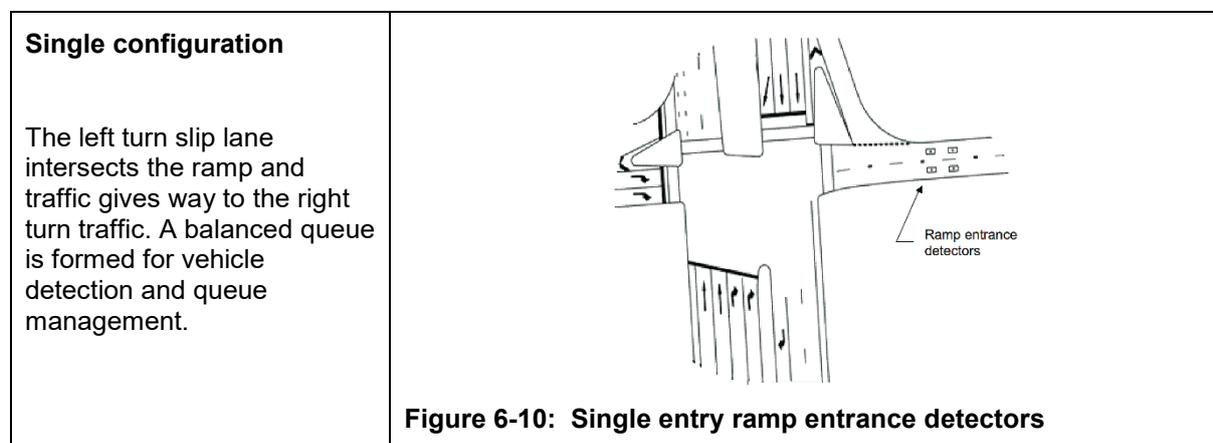
Mid ramp detectors are not provided on metered priority access lanes as the priority traffic (with short or no queue) is not considered in relation to the queue management for the general traffic lanes.

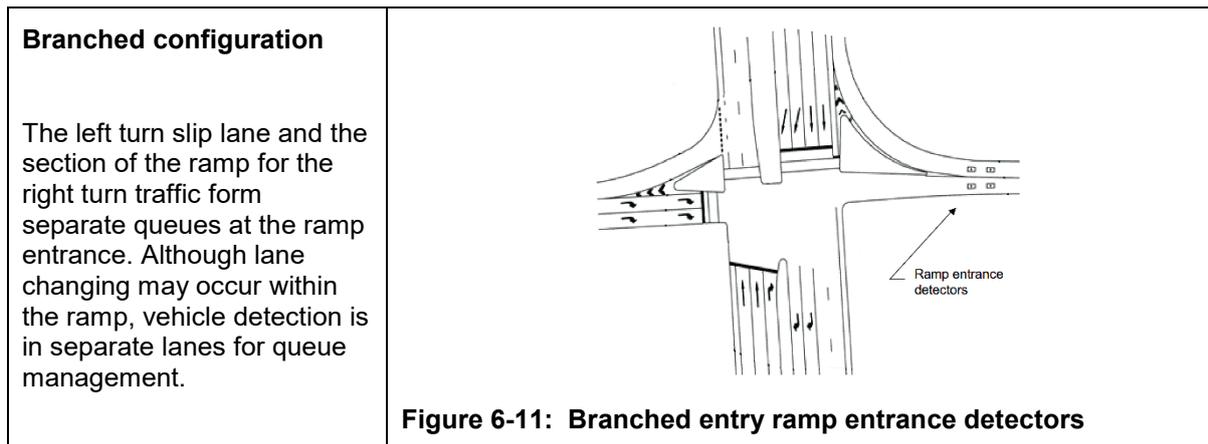
6.10.4.3 Ramp Entrance Detectors

Detectors are provided at the ramp entrance for queue length estimates and queue management in the ramp signal control algorithm. Generally, they are also used to determine when ramp queues may overflow onto the surface road.

The ramp entrance detectors are positioned to suit the type of layout at the ramp entrance as shown in Figure 6-10 and Figure 6-11. The layouts are treated differently within the control algorithm.

For a long ramp, i.e. significantly longer than the desirable minimum 4 minute queue storage distance, the 'ramp entrance' detectors are placed at the calculated 4 minute queue distance.





6.10.4.4 Queue Overflow Detectors

Whenever possible the motorway ramp storage should be designed to accommodate the estimated minimum desirable storage requirements as outlined in Section 6.3 to avoid queues overflowing into the surface road. When this cannot be achieved, consideration may need to be given to installing separate queue overflow detectors on the surface road. Queue overflow detectors may also be needed on ramps longer than the minimum desirable storage length, in addition to the ramp entrance detectors.

The ramp signal control algorithm is generally set up to use the ramp entrance detectors in a dual role. This enables them to function as ramp entrance as well as queue overflow detectors. Where separate queue overflow detectors are provided, the ramp entrance and the queue overflow detectors both need to be occupied to activate the queue override facility in the algorithm.

Where the ramp is very short relative to the desirable storage, queue detectors may need to be provided on the surface road at the start of the right and/or left turn lanes leading to the ramp.

For a long ramp, i.e. significantly longer than the desirable minimum 4 minute queue storage distance, the queue overflow detectors are generally installed at the ramp entrance.

Further guidance relating to ramp detectors on motorway-to-motorway ramps is in Section 7.7.3.

Background Note:

An interface with the traffic signal control system, SCATS, is available to obtain information from the signal detector loops on the surface road. The interface also enables transfer of information from the ramp detectors to the SCATS traffic signal system to enable control of the interchange signals according to predetermined control actions or strategies.

6.10.5 Collector Distributor Road Entry Ramp Detectors

Where the connection from a collector distributor road is metered to manage traffic entering the mainline, vehicle detector locations are generally determined according to the same principles as for a long ramp, i.e. the 'ramp entrance' detectors are placed at the calculated 4 minute queue distance and queue overflow detectors as outlined in Section 6.10.4.4 are also provided for queue management and to prevent queues interfering with an upstream ramp on the CD road.

For a CD road to be managed with ramp signals (servicing of closely spaced entry and exit ramps or a separated carriageway - refer Section 3.7), the vehicle detection shall be provided according to the same principles used for mainline detection as outlined in Section 5.1.

6.10.6 Poles for Wireless Detector Receivers

Access points (APs) receive the wireless data transmissions from the wireless vehicle detectors and repeater points (RPs). APs require cabling back to the field processor and are generally mounted on an appropriately located cantilever structure, JUP or gantry near the field processor and signal controller. The AP is installed near the top of the pole at a height of 8 metres (minimum 6 metres).

Repeater points (RPs) are wireless devices that receive transmissions from the vehicle detectors and then transmit the data to the AP. Generally RPs are installed at a height of 8 metres (minimum 6 metres) and may be installed on an appropriately located cantilever structure, JUP or on a separate pole as appropriate. Subject to roadside safety design considerations, poles in the clear zone should be frangible or shielded with a safety barrier. The use of slip base lighting poles in vulnerable locations is generally avoided due to potential delays replacing poles after a crash.

6.10.7 Ramp Control Signs

Motorway ramp metering signals are part-time traffic control devices and motorists need to be advised when the signals are operating. Real time traveller information is also important to advise drivers of travel times and traffic conditions on the motorway.

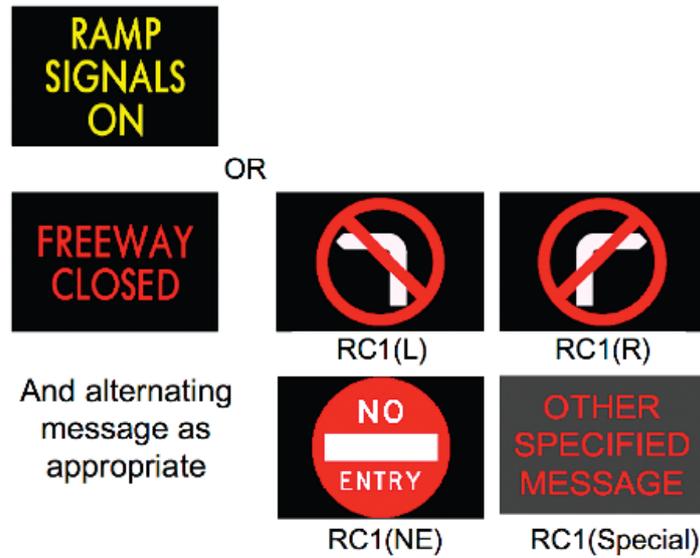
The following dynamic electronic ramp control signs are provided as part of the ramp signals design to provide warning, real time traveller information and incident management:

RC1	RC2	RC3 (or RTIS)
<ul style="list-style-type: none"> • Warning message when the ramp signals are operating • Regulatory and advice messages when the motorway ramp is closed. 	<ul style="list-style-type: none"> • Warning messages when the ramp signals are operating. 	<ul style="list-style-type: none"> • Traveller information relating to: <ul style="list-style-type: none"> • Travel time (default) • Motorway condition, i.e. level of congestion • Incidents and events. • Motorway closure information.

6.10.7.1 RC1 Warning and Regulatory Sign

The RC1 warning and regulatory signs display a 'RAMP SIGNALS ON' message as shown in Figure 6-12 when the ramp signals are operating. Separate signs are provided at the surface road / entry ramp intersection to face right and left turning traffic turning into the ramp. At a roundabout, the RC1 sign is provided at the ramp entrance as it leaves the roundabout, at a location where it is visible to motorists on the circulating roadway prior to exiting.

The RC1 signs have a dual role and can also be activated for operation as part of motorway incident management to display 'FREEWAY CLOSED' and a symbolic No Right/No Left Turn, No Entry or other specified message, as appropriate.



Note: TOLLWAY CLOSED or FREEWAY CLOSED display is used as appropriate.

Figure 6-12: RC1 Sign Messages

6.10.7.2 RC2 Warning Sign

RC2 warning signs are used on an entry ramp for situations where there is restricted sight distance to the ramp signals. The sign arrangement indicates traffic signals ahead via a static symbolic sign W3-3B sign mounted above a supplementary electronic message panel with alternating text 'PREPARE TO STOP' and 'RAMP SIGNALS ON', as shown in Figure 6-13.



Figure 6-13: RC2 Entry Ramp Warning Signs with Alternating Messages

6.10.7.3 RC3 Sign - Real Time Information Sign (RTIS)

RC3 ramp control warning and information signs are a mandatory component of all ramp signal designs and ramp control functionality.

The RC3 signs provide a constant indication of the downstream status and operation of the motorway system (24/7) advising motorists of travel conditions for between 5 and 15 kilometres from the point of entry. The coordinated ramp metring system means signals are able to be switched on anytime as traffic demands fluctuate at points across the motorway network.

These real time information signs are multi-colour full matrix variable message signs which provide up to 3 lines of text and/or graphics within a display matrix of 1536mm x 480mm. The signs display travel time information on the motorway, including ramp delay, and contribute to the motorway management during periods of congestion or incidents. Examples of RC3 sign displays are shown in Figure 6-14. Further information is included in the Managed Freeways Handbook for Lane Use Management, Variable Speed Limits and Traveller Information (2013).

Advising the public in real time of travel time, incidents and roadworks can influence motorists into using alternate routes by providing the opportunity for drivers to make informed travel choices. This not only reduces individual inconvenience experienced by waiting in slow moving traffic, but has the potential to reduce the demand on mainline flow and improve safety associated with advance warning of motorway conditions after a motorist enters the motorway, e.g. left lane closed. Being able to manage the motorway during events also facilitates faster recovery of the motorway after an incident. The RC3 signs are dedicated ramp and motorway management devices and are not to be used for other VMS messages for other purposes.

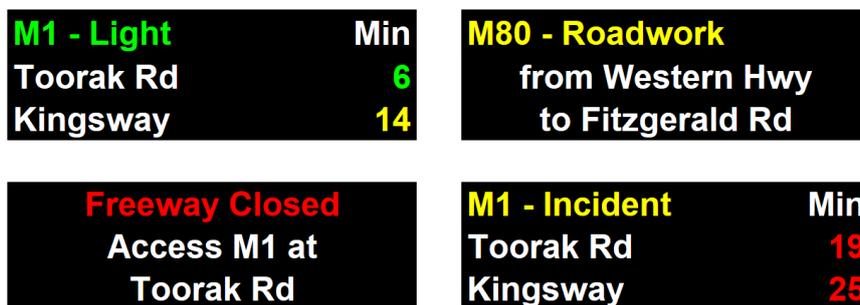


Figure 6-14: Examples of RC3 Real Time Information Sign Messages

An RC3 sign is provided on the surface road for each movement onto the motorway. Subject to VicRoads agreement (refer Volume 2, Part 1), an RC3 sign may not be necessary for a movement where downstream travel time data on the motorway is not available, e.g. near the outer limits of the managed motorway.

RC3 signs are located on the surface road according to the following principles:

- Separate signs are provided for all movements into metered ramps at a desirable distance in the order of 80m to 150m prior to the left and right turn lanes at the interchange, subject to consideration of the speed limit. If there are no left and/or right turn lanes for the turning movement, the RC3 signs should be at a similar or greater distance prior to the intersection.
- At a roundabout interchange, separate signs are provided on each surface road leg approaching the roundabout, desirably 80m to 150m (or further if required) prior to the reaching roundabout subject to consideration of the speed limit.
- When the interchange is relatively close to a downstream motorway fork, i.e. one or two interchanges prior to the motorway dividing into two routes, two RC3 signs are provided for those movements to enable separate displays of travel time and incident information for each downstream route.

Locating RC3 signs may be problematic due to driveways, intersections and median openings etc. Every effort should be made to provide an adequate distance prior to the decision point so that motorists have advanced information to make a decision on route choice.

Where a motorway interchange complex has a complicated ramp layout and / or circuitous surface road access, provision of RC3 signs may need to be positioned in locations that differ from those indicated on standard drawings. Positioning of RC3 signs needs to consider the provision of sufficient traveller information to enable drivers to make alternative route choices within the localised road network context, especially in the event of significant delays or ramp closures. Where ramp terminal intersections provide access to multiple metered ramps with different destinations, an RC3 panel for

each ramp is required to enable ramp specific messages and directional travel information. In such scenarios, VicRoads approval of proposed provisions and locations is required.

RC3 signs are generally installed on an RC3 pole (refer VicRoads Standard Drawings) or a joint use signal pole (JUP) as appropriate. Where a median or footway is of insufficient width to provide the minimum of 500mm lateral clearance from the sign to the kerb-line, the RC3 may be installed on a mast-arm (generally with 2.5m outreach) so that the sign is cantilevered over the roadway (minimum vertical clearance 5.4m or 5.9m on an over dimensional route).

Background Notes:

An Instinct and Reason report prepared for Austroads (Austroads, 2008) relating to research on road user information needs with an emphasis on variable message signs, indicated that 80% of participants would find travel time in minutes useful and that 79% would find the colour coding of traffic flow useful.

A Sinclair Knight Merz report (2005) based on focus group discussions relating to the Drive Time System indicated that “The ‘minutes’ information was considered most valuable to regular road users whereas the ‘colours’ based information was thought to be most useful to infrequent users.”

6.10.8 Signing of Ramps on Roads forming a Direct Motorway Connection

Arterial or other surface roads that form a ramp connecting directly to the motorway (example in Figure 6-15), rather than via a typical ramp entry at a terminal intersection, may need a higher standard of advance information, warning and regulatory signs, compared to a conventional entry ramp. These traffic movements onto the motorway are generally significant.

These ramps are generally characterised as having no defined ramp entrance as the continuing lanes from the roadway feed directly into the motorway, or into a motorway-to-motorway connector ramp. In such cases, they may effectively feel and operate similar to motorway-to-motorway connector ramps both in terms of geometry and driver behaviour.

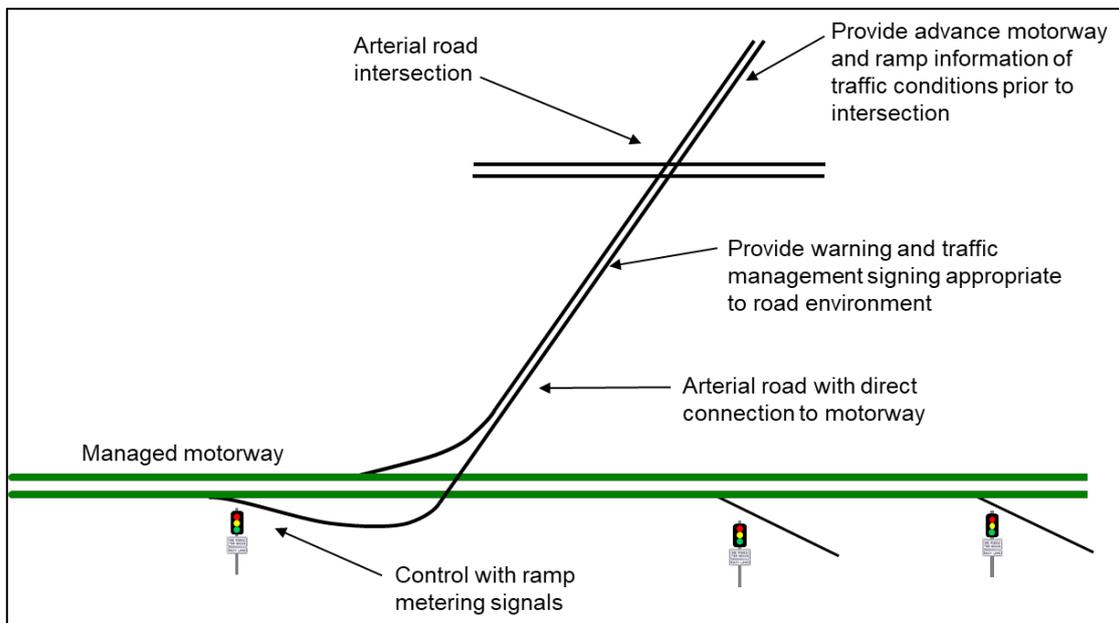


Figure 6-15: Example of a Continuing Road forming a Motorway Entry Ramp

For these ramps, and subject to the road environment, traffic volume and nature of the route, the following signing principles could be considered which take a similar design approach to requirements for motorway-to-motorway ramps (refer Chapter 7):

- Advance VMS signing to provide information to motorists relating to the conditions ahead (refer Section 7.6 relating to RC3-C signs). This advance sign would indicate when the ramp signals are on and should be provided prior to the upstream intersection on the major road. This location provides information and opportunity for motorists to change their route when necessary, e.g. when the ramp is closed or there are major delays or an incident.
 - Note: the smaller standard size RC3 used for conventional surface road ramps is considered too small for this purpose so generally a larger size (which at the time of publishing is under consideration and development) is suitable for an 80 km/h arterial road environment.
- A variable speed limit may be appropriate on the approach to the signals to enable the speed limit to be stepped down, e.g. from 80 km/h to 60 km/h, when the ramp metering is operating. VSL sign(s) would also be provided downstream of the ramp signals to indicate the applicable speed limit of the motorway being entered.
- Overhead lane control would generally not be needed unless the motorway that the ramp is entering has lane use management. This would also be subject to the width of the approach (e.g. 3 or 4 lanes of storage), the geometry and the road environment.
- Larger RC2 warning signs (refer Section 7.4 for RC2-C signs) may also be desirable based on the speed and road environment.

6.10.9 Other Signs

Other static or electronic signs shown on the drawings as forming part of the ramp signals installation include:

- Stop Here on Red Signal (R6-6A)

These regulatory signs are required at the stop line as it is remote from the traffic signals.
- One Vehicle Per Green Each Lane (G9-V198)

This sign is located on the signal pedestal near each lantern and also overhead between lanterns (refer to standard drawings for details).
- Form One Lane (G9-15B), or Form Two Lanes (G9-16B), as appropriate.

These signs are generally located 20 metres downstream of the stop line.
- Speed limit sign (R4-1B) or variable speed limit sign.

These signs are generally located 20m prior to the ramp nose to indicate the speed limit on the carriageway being entered.

Speed limit signs must be installed on both sides of the ramp where two lanes are present at the ramp nose, or where more than one lane exists at the location where the signs are provided to ensure all drivers can sight a sign within the merge area downstream of the stop line.
- Truck Lane signs (or Bus Lane signs as appropriate) to designate the use of the left lane as a priority access lane if provided.

The use and positioning of these signs is consistent with Rule 329 of Road Safety Road Rules (Victorian Legislation and Parliamentary Documents, 2009). If installed adjacent to the lane, the signs are supplemented with a 'Left Lane' sign if appropriate.



Other signs which may be required in association with a motorway entry ramp, e.g. Merging Traffic warning sign, Emergency Stopping Lane sign etc. shall be provided in accordance with the VicRoads standards.

6.10.10 Pavement Markings

The pavement markings and retro-reflective pavement markers (RRPM) associated with the ramp signal designs as shown on the Standard Drawings are provided according to the VicRoads standards and the following principles:

- Longitudinal line marking includes a 30 metre single continuous lane line on the approach to the stop line.
- Edge lines are provided on both sides of the ramp. Downstream of the stop line the left edge line provides guidance for the merging traffic.
- The two to one lane merging downstream of the stop line is a 'zip' merge, i.e. no continuity line is provided.

- The merging from the entry ramp into the main carriageway of the motorway is a lane changing movement, i.e. provide a continuity line.
- The stop line is located 10 metres upstream of the traffic signal pedestal.

6.10.11 CCTV Cameras

The provision of a CCTV camera with pan, tilt, and zoom capability is included in the ramp signal design to facilitate operator observation during fine tuning of algorithm operation and to enable surveillance and monitoring queues, driver behaviour and operations. CCTV coverage is also essential for observing conditions during incidents, maintenance activities or roadworks. Camera coverage of traffic conditions and the motorway environment shall include visibility:

- Along the full length of the controlled ramp
- At the metering stop line to observe driver behaviour and ramp meter operation
- On the surface road approaches, i.e. the left and right turn lanes in case of queue overflow
- At the motorway entry, up to and including the end of the ramp merge taper or for a similar distance if the entry has added lanes.

All interchange arrangements are unique in some regard and one or more cameras may be required to meet the above requirements.

A camera at the interchange near the ramp entrance generally provides the best coverage of these areas for ramp metering. A camera may be included on the cantilever or gantry pole extension as appropriate. While this camera location provides a solution at relatively low cost, it would generally not provide a view of the surface road approaches. Cameras should generally be located within 80m of the controller to facilitate data communications.

6.10.12 Power Supply and Communications

The power supply connection to the ramp signal controller is provided from an Electricity Supply Authority point of supply. Power is then distributed to other devices. A separate local power supply may be provided to RC3 signs.

Electrical conduits (E100mm orange) and communications conduits (C100mm white) generally connect devices to the controller. Separate pits are provided for the communications and power. Pits are provided at all changes of direction and at a maximum spacing of 250m on straight lengths.

The preferred arrangement for system control is the use of fibre optic communications in mainline trunk conduits. In some situations a wireless communication network may be necessary.

6.10.13 Lighting

Generally, street lighting is not specifically required as part of the installation of motorway ramp metering signals. The need for lighting of the entry ramp may need to be considered in accordance with VicRoads freeway lighting policy and guidelines.

Volume 2: Design Practice
Part 3: Motorway Planning and Design

Chapter 7: Motorway-to-Motorway Ramp Metering
Signals



7 Motorway-to-Motorway Ramp Metering Signals

7.1 Introduction

The performance of a Managed Motorway is determined by its ability to prevent and minimise flow breakdown, to perform well under stress and to recover as soon as possible in the event of congestion occurring. This means designing the infrastructure to minimise the potential for flow breakdown and providing facilities to manage traffic demand and flow within the motorway's capacity.

The general principle for optimising route performance is to control and regulate all traffic entering a managed motorway, including traffic from motorway-to-motorway (system) ramps which are generally high flow ramps which have the potential for delivering large uncontrolled flows to bottleneck areas. The coordinated ramp signals system is then able to best manage flow to an optimum level along the whole route and coordinate the operation at all ramps to balance priority, equity of access, queues and waiting times.

VicRoads experience of having uncontrolled high flow motorway to motorway ramps (i.e. the initial installation on the Melbourne motorway network) is that whilst bottleneck activation can be delayed, it is generally not feasible to prevent flow breakdown. Furthermore, once flow breakdown has occurred, the continued uncontrolled high flow will worsen the congestion and further delay the flow recovery and the potential occurrence of significant lengths of congestion and reduced safety to occur on one or both motorways. Under this scenario, generally all other ramps along the route need to take an inequitable share of the management load.

In view of the importance of safety and operation of system interchanges all designs shall be subject to a design report covering design matters in this Guide and be subject to approved by VicRoads Roads and Traffic Design Department.

7.2 Control of Motorway-to-Motorway Ramps

As flows entering a Managed Motorway from another motorway would contribute to the potential for flow breakdown on the managed motorway, ramp signals generally need to be provided as outlined in the sections below. Where ramp metering is provided it would only operate when needed and uncontrolled free-flow operation would be available at other times. If flow breakdown does occur on the Managed Motorway this would impact not only the Managed Motorway but also potentially impact traffic from the intersecting upstream motorway, therefore justifying management of all entering flows appropriately, i.e. the high intensity traffic spikes at the 20 seconds to 1 minute level may be a cause of flow breakdown. The absence of control increases the potential for these vehicle clusters triggering the bottleneck flow breakdown.

In view of the nature of operation of motorway-to-motorway ramps with relatively high traffic speeds, the ramp signal design and operations employ a number of traffic management devices to provide warning and manage speed for safe operations.

Metering the upstream entry ramps from surface roads, rather than the motorway-to-motorway ramps, may be a workable strategy for managing the motorway-to-motorway merge and downstream sections of motorway (refer Section 7.2.1), subject to the analyses of the adequacy of being able to manage mainline operation and safely manage and contain ramp queues. However, where the intersecting motorway does not have upstream entry ramp signals or where the upstream ramp metering is unable to provide the necessary control to manage downstream flow on the mainline, i.e. based on analysis for a partially managed system, motorway-to-motorway ramp metering should be provided or other options considered if volumes are too high for control (i.e. design flows are significantly higher than applicable discharge flow rates outlined in this guide).

The provision of metering at upstream surface road entry ramps compared with metering at an entry ramp from an intersecting motorway may also require an understanding of travel patterns or typical trip lengths on the motorway. The traffic implications need to be considered and this may involve an origin-destination study of the motorway trips associated with traffic entering the Managed Motorway from the intersecting motorway.

Further advantages of metering motorway-to-motorway ramps are that it would assist in the ability to manage traffic during incidents and improve recovery from congested conditions after an incident.

Managed motorways are generally only effective when traffic is controlled at all points along a route. Effective control of traffic occupancy, particularly at critical bottlenecks, means that control needs to be provided close to where problems are likely to occur.

Critical bottlenecks can often be triggered in the section or sections immediately downstream of a motorway-to-motorway ramp due to the high entering flows, and the most effective means of preventing or recovering from instability is having the nearest upstream ramp(s), i.e. the motorway-to-motorway ramp, directly managing the bottleneck. This requires the motorway-to-motorway ramp operation to initiate in a timely manner to minimise the probability of flow breakdown. In order to manage high flows from motorway-to-motorway ramps, other upstream ramps on the Managed Motorway need to activate concurrently. The ramps working together as a system improves the ability to provide high discharge flows from the system ramp when this is necessary.

An important requirement for the provision of motorway-to-motorway metering is that a motorway-to-motorway metering site shall always be provided in conjunction with upstream and / or downstream metering sites on ramps from surface roads to provide a system response and support the motorway-to-motorway ramp operation. Managed motorway design and operations shall not rely on an isolated motorway-to-motorway ramp meter to control bottlenecks. For clarification, the supporting ramp meters from surface road entry ramps are those that enter the same route as the motorway-to-motorway ramp.

7.2.1 Interchanges where Motorways Join

Where the intersecting motorway joins with the Managed Motorway at a Y-Interchange, as shown in Figure 7-1 and Figure 7-2, the traffic from ramps immediately upstream of the interchange make a significant contribution to the flow entering the managed motorway. Options to manage these interchanges are:

- Metering of several upstream ramps on each motorway to control the traffic at the interchange merge as well as the downstream section of motorway (refer to Figure 7-1); or
- Direct metering of the traffic from the lower volume unmanaged motorway connection to the higher volume motorway (refer to Figure 7-2);
- A combination of both forms of control above subject to the analyses of the adequacy of being able to manage mainline operation and safely manage and contain ramp queues.

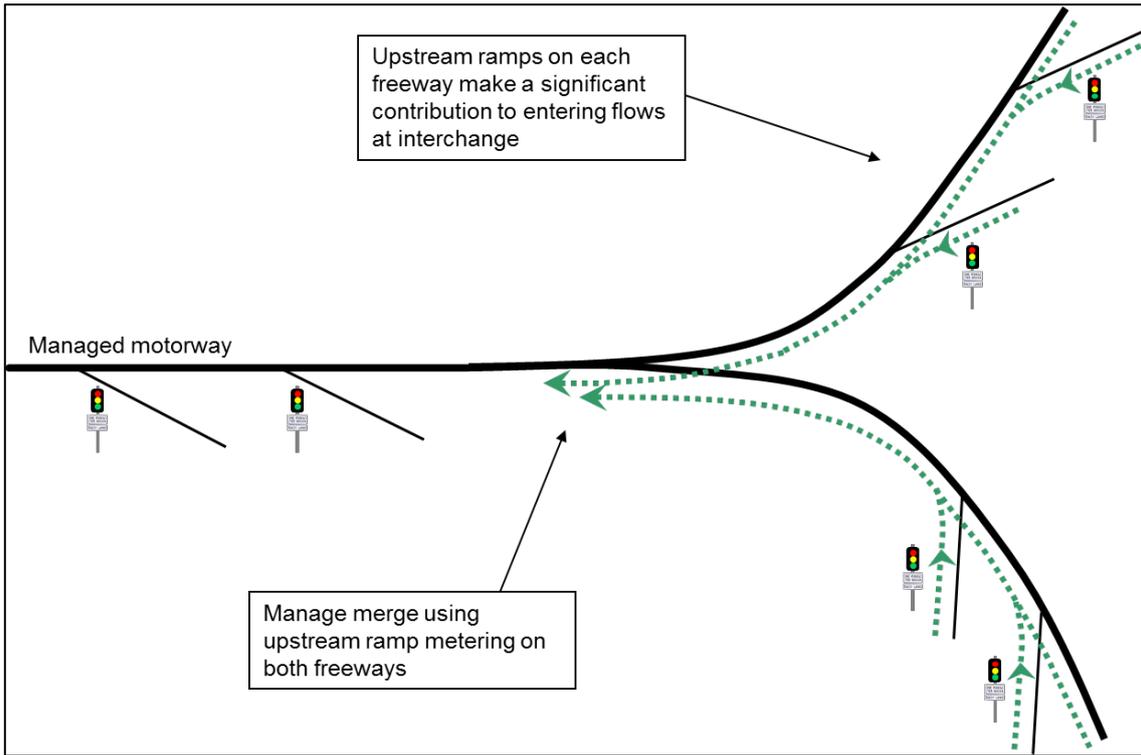


Figure 7-1: Ramp Metering at Two Managed Motorways that Join

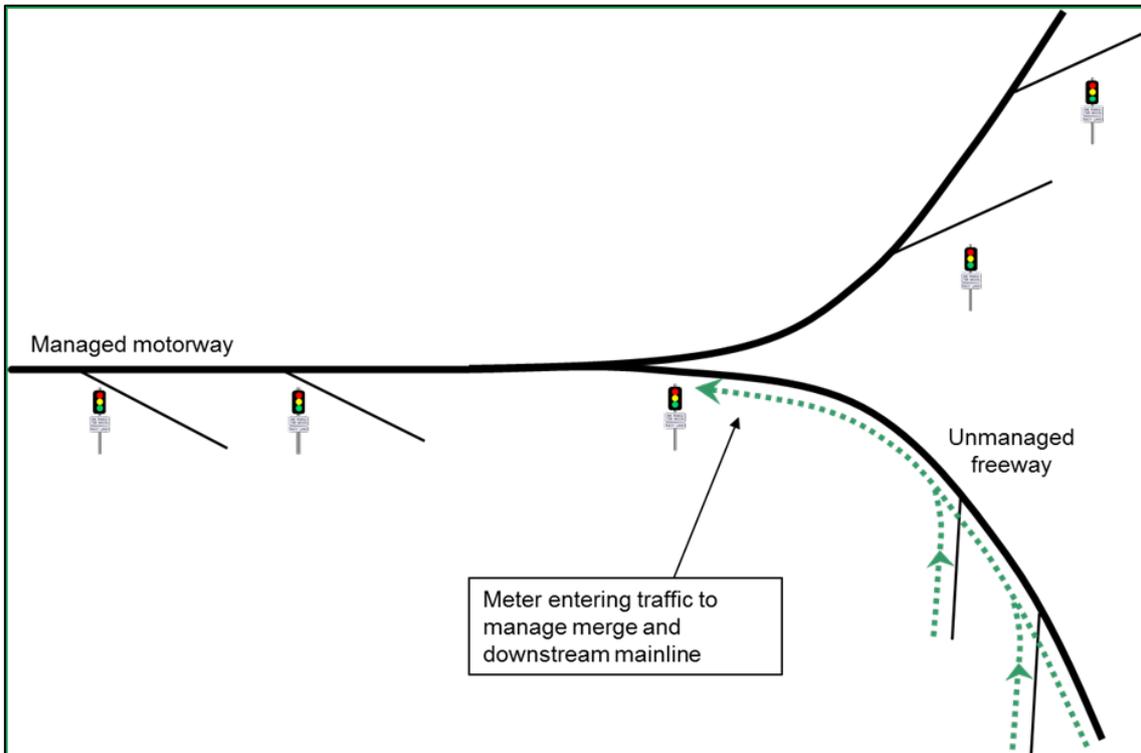


Figure 7-2: Ramp Metering at an Unmanaged Motorway Joining a Managed Motorway

7.2.2 Interchanges at the Start or End of a Motorway (T-Interchange)

Where a motorway terminates at an interchange in the form of a T-Interchange (refer Figure 7-3), operational priority is generally given to the route which forms the 'through movement' at the interchange, i.e. the continuing motorway with the highest traffic flow. For this form of interchange:

- The turning traffic on ramps from the terminating motorway (stem of the 'T' heading towards the system interchange) would be ramp metered where it enters the managed motorway. For control, this is preferable to metering of upstream ramps on the terminating motorway to assist in downstream mainline management of the Managed Motorway as this could disadvantage traffic travelling in the opposite direction where control may, or may not, be needed. However, there would generally be an advantage for the terminating motorway itself, if all upstream ramps were metered.
- If the commencing motorway (stem of the 'T' heading away from the system interchange) is managed, the turning traffic on ramps from the continuing motorway into the Managed Motorway (stem of 'T'), should be metered to facilitate downstream mainline management. Generally, as a minimum the lower traffic flow shall be metered into the higher traffic flow movement. In some cases, both may need to be metered.

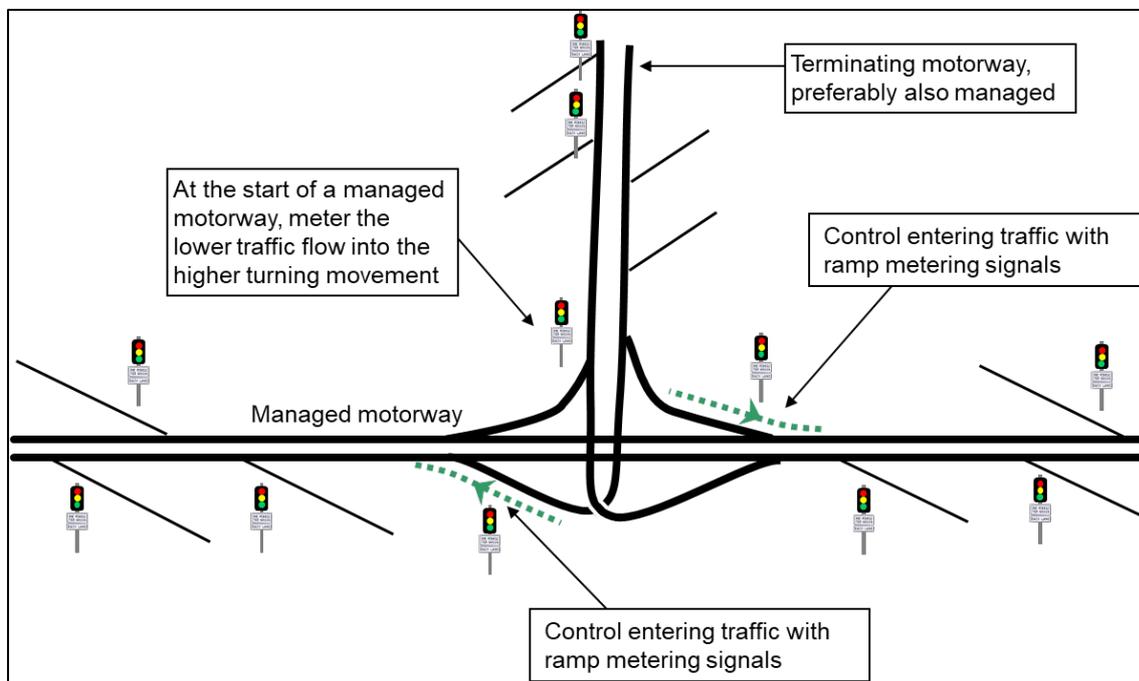


Figure 7-3: Ramp Metering at a 'T' Junction System Interchange

7.2.3 Interchanges where Motorways Cross

For interchanges where a major traffic flow crosses the managed motorway (flow from top to bottom as shown in Figure 7-4), metering of the upstream ramps on the crossing motorway would generally not provide the desired level of control for the managed motorway (flow from right to left in the figure) as the ramps immediately upstream of the interchange would make a lower traffic contribution to the exit ramp flows at the interchange. The metering of upstream ramps on the crossing motorway would also disadvantage traffic that is not exiting to the managed motorway.

In this situation ramp signals on the motorway-to-motorway ramp would be required for effective control of entering flows at the ramp entry as well as control of the downstream sections of the managed motorway.

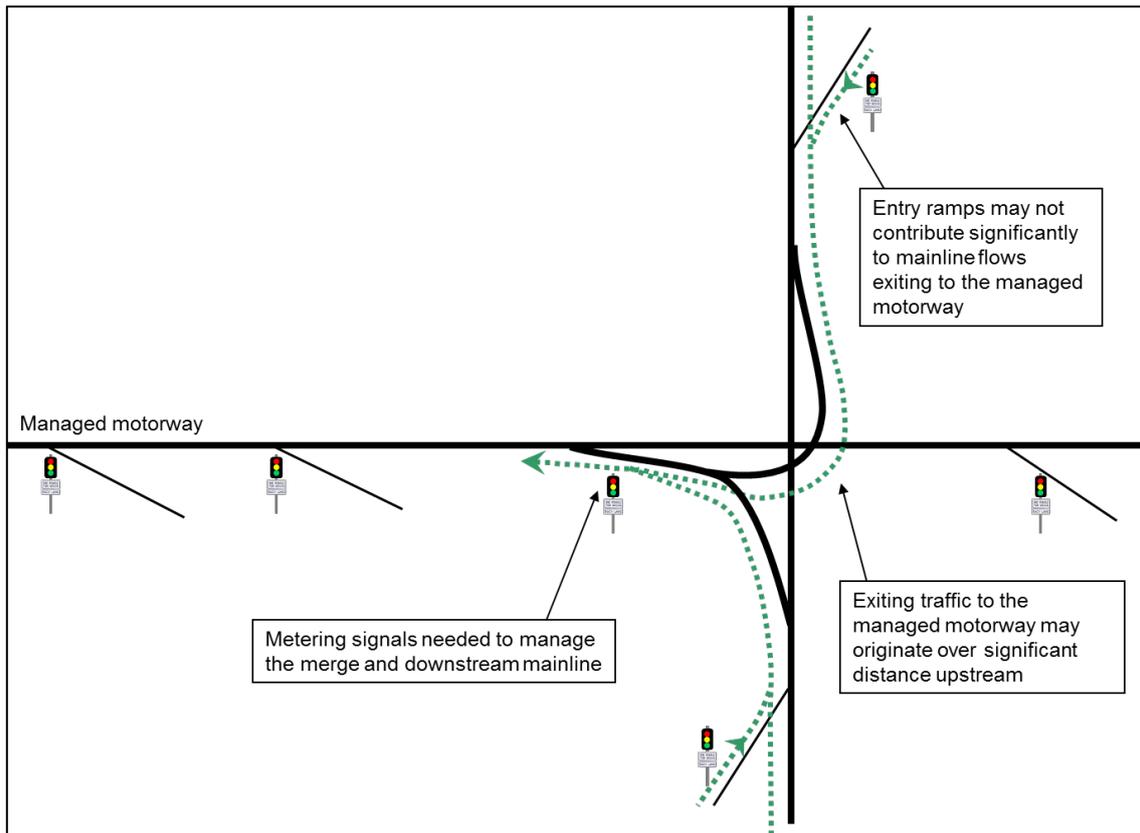


Figure 7-4: Ramp Metering at Motorways that Cross

7.3 Ramp Geometry and Signal Layout

7.3.1 General Layout

There can be significant challenges related to ramp metering of motorway-to-motorway ramps including presence of structures and widening of embankments. There are also operational implications due to managing safety, high traffic flows, providing the ramp discharge and storage required and in operations, balancing queues and delays between coordinated ramps.

Figure 7-22 shows an indicative motorway to motorway layout including locations of freeway ramp signals and other traffic management devices.

7.3.2 Stop Line and Traffic Signals Location

The stop line location relative to the ramp nose is determined according to the principles and typical arrangements provided in Sections 6.1 to 6.8. Traffic signals are located downstream of the stop line consistent with layouts for ramp signals on entry ramps from surface roads on a cantilever, gantry or poles, subject to the number of lanes required.

The detailed layout and geometry for ramp signals on motorway-to-motorway connector ramps would be developed according to the standard drawings for two, three or four lanes, as appropriate. Where two ramps join within the interchange prior to entering the Managed Motorway as shown in Figure 7-5, the following options for the location of the ramp signals may be considered:

- Using separate signals/stop lines for the left and right turning ramp connections just upstream of where they meet within the interchange. This option enables each ramp to be managed separately with queue lengths and/or waiting times balanced between the two ramps. As this option would generally result in shorter distances available for storage development it should only be used where the desirable minimum storage is available.

- Using a single stop line downstream of the merge between the two ramps after they form a single entry ramp onto the managed motorway. With this option storage should be provided on the combined section and can extend upstream on both connector ramps. Consideration also needs to be given to how the lanes from the two upstream ramps are configured to cater for potential differences in traffic demands from each direction. Design also needs to consider the combined flows from two or more upstream connector ramps and ensure total flow can be managed.

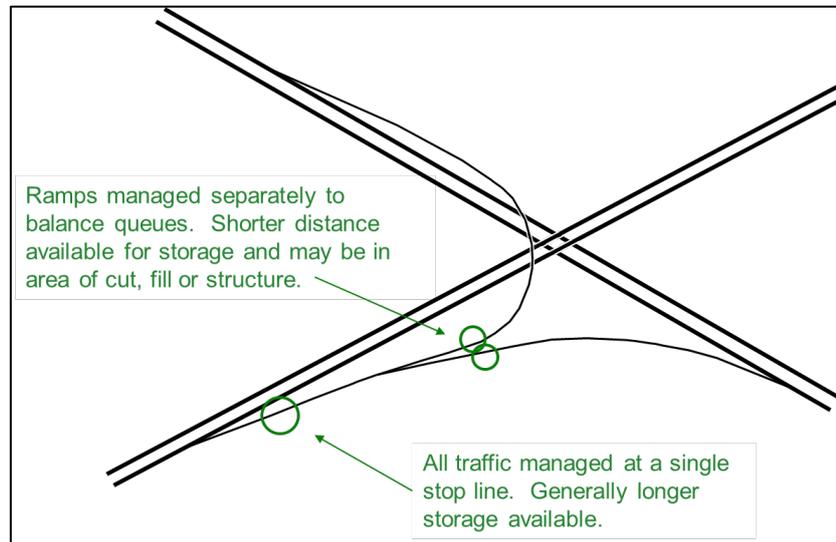


Figure 7-5: Typical Motorway-to Motorway Ramp Signals Locations

7.3.3 Stopping Sight Distance

Road design guidelines require that stopping sight distance is provided when entering the ramp from the adjoining motorway as well as along the ramp itself. Therefore, back of queue visibility at any point along the ramp is generally provided with stopping sight distance based on the deceleration of a vehicle from the motorway speed to a stopped condition.

Where ramps provide storage in auxiliary lanes, stopping sight distance shall also be provided to queues in the additional storage lanes being provided, based on the appropriate operating speed when the ramp signals are on (refer Section 7.5.2).

7.3.4 Discharge Capacity and Storage

The determination of the number of lanes at the stop line (discharge capacity) and the desirable minimum ramp storage shall be determined according to requirements in Section 6.2 and Section 6.3 respectively, as well as the requirements in this section. This is to ensure that motorway-to-motorway ramps operate:

- With a high level of efficiency and provide timely operational responses that suit a range of traffic conditions;
- To enable high ramp flow rates and minimal delays when this can be accommodated by the system;
- To enable queue management that will avoid queues extending beyond the storage area, i.e. minimise safety concerns and potential for interference with upstream traffic movements.

7.3.4.1 Discharge Capacity at the Stop Line

The following design principles shall be applied in determining the number of lanes at the stop line:

The number of lanes at the stop line shall satisfy the maximum hourly forecast design volumes with operation in the desirable range of cycle time, i.e. the black range of cycle time in Table 6.1;

- Consideration should be given to providing spare capacity, particularly if this facilitates the design of storage or allowance for traffic growth;
- If the hourly design peak flow is in the order of 2,500 veh/h or more, the ramp metering design may need to consider specific non-standard operation as indicated in Section 6.2.1.

7.3.4.2 Ramp Storage

To following design principles shall be applied:

- The desirable minimum storage is to provide at least 4 minutes storage based on the maximum hourly forecast design volume;
- Preferably, the storage provided should be greater than the desirable minimum, particularly if adequate storage cannot be provided at other ramps within the coordinated ramp signal system along the route, i.e. to compensate for the lack of storage elsewhere;
- Layouts with short auxiliary lanes at the stop line may be appropriate according to ramp length and traffic demand. For high flow ramps, storage designs may include increased length of storage in longer auxiliary lanes with appropriate traffic management (refer Section 7.5), rather than using short auxiliary lanes;
- For a ramp that divides into two ramps (fork) for traffic travelling in two directions as shown in Figure 7-6, the storage upstream of the stop line on the metered connection should desirably be provided within the controlled section of the ramp so that a queue will not interfere with the traffic diverging to the other ramp connection beyond the bifurcation. Where this is not practicable, consideration should be given to widening and providing dedicated lanes so that free-flowing traffic using the other ramp connection is not affected by the ramp metering queue;
- In some instances, extending or widening a system ramp may be necessary to achieve the minimum desirable storage and to ensure safe operations.

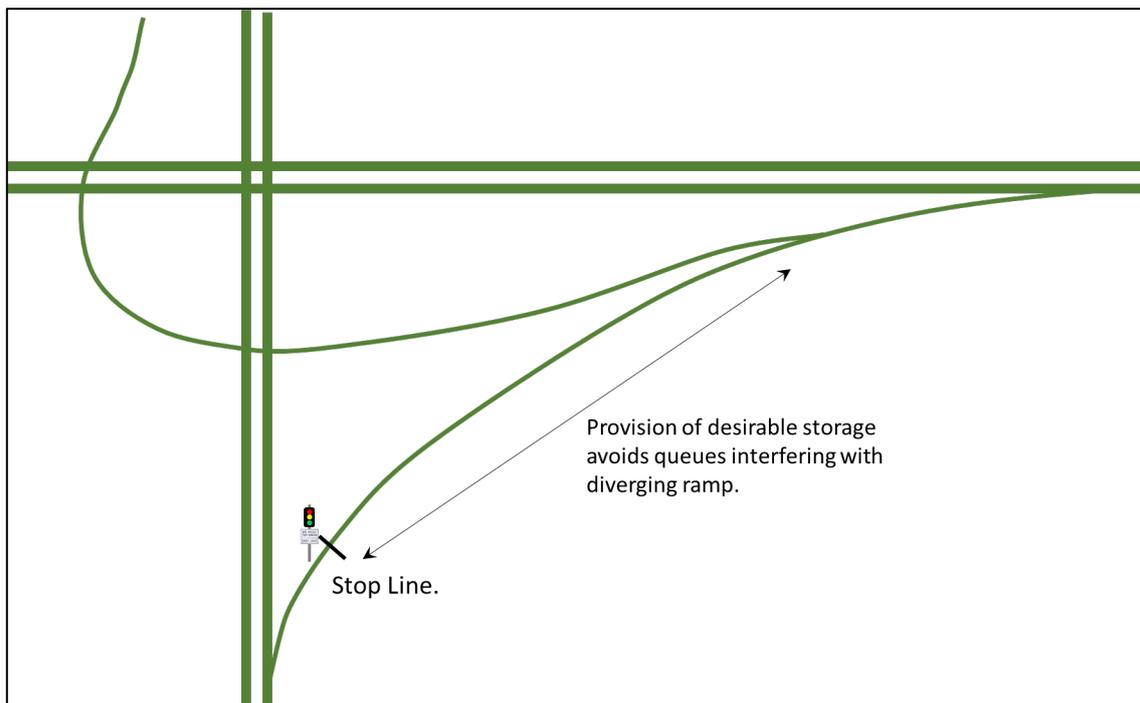


Figure 7-6: Desirable Storage Provision prior to a Ramp Bifurcation

7.4 RC2-C Warning Signs

7.4.1 Sign Purpose and Functionality

Variable message signs are provided on the ramp to warn approaching motorists that ramp signals are on and that they may need to stop.

The RC2-C (size range Type C) sign message indicates 'RAMP SIGNALS ON' (yellow on black) alternating with 'PREPARE TO STOP' (red on black). When the ramp signals are off the sign display is blank. The messages are the same as the RC2-A sign displays used on some surface road entry ramps, but are larger due to the speed environment.

The RC2-C signs use a minimum display font size of 190mm high (upper case). An RC3-A sign specification (sign matrix 128 pixels wide and 40 pixels high) is generally used for the RC2-C sign.

The RC2-C sign is generally not used for provision of other traveller information, e.g. incidents, relating to the ramp or downstream motorway. However, information may be considered for display on the upstream motorway to provide information to motorists prior to exiting (refer Section 7.6).

7.4.2 Sign Location and Installation

The RC2-C signs are co-located on the ramp with the variable speed limit (VSL) or overhead lane control signs. A traffic signals ahead warning sign (W3-3C static symbolic sign) is also typically provided where VSL signs are mounted overhead to reinforce that the signals may commence operation at any time. Typical sign arrangements are shown in Figure 7-7 for:

- Side mounted: Typically used for installation adjacent to single lanes on ramps;
- Overhead mounted on a cantilever structure: Typically used for multilane ramps where the sign installation over the lanes generally maximises sight distance. A cantilever is generally desirable to minimise hazards and a need for safety barriers to be provided on both sides of the roadway. A gantry may be appropriate for some installations.



Note: RAMP SIGNALS ON (yellow) alternates with PREPARE TO STOP (red)

Figure 7-7: RC2-C Sign Arrangements for Single and Two Lane Ramps

The signs are provided at the start of the ramp and then repeated at other locations along the ramp upstream of the signals as shown in Figure 7-8 and Figure 7-9.

The initial sign arrangement will generally be provided in the order of 50m downstream of the exit nose with a minimum separation distance of 100m from the exit direction sign across the gore area (GE2-V1 series sign or equivalent). This location enables display of the necessary warning and information prior to a road user encountering slower moving traffic or the back of a queue.

Upstream of the stop line the lane control and RC2-C signs are generally provided at a minimum of two (2) locations along the ramp subject to ramp length and a typical minimum spacing of 150m. More locations may be required where the ramp branches into two or more ramps for different directions of travel.

Where a ramp widens to provide long auxiliary lanes for storage, either after the exit or at some other location along the ramp:

- The RC2-C and lane control signs shall be located at the start of the auxiliary lane(s) on the widened cross section (generally at end of taper) to facilitate lane control along the ramp.
- A further sign would generally be positioned between the initial sign at the start of the auxiliary lanes and the stop line.

Where the exit ramp divides further downstream from the exit nose for traffic to travel in different directions, the initial sign at the exit ramp nose may, or may not, be relevant to the motorists' travel. The signage principles are generally focussed on:

- The highest traffic movements using the ramp (typically leading to the ramp signals), even though the message may not be applicable to all road users.
- The safest arrangement to provide warning as early as possible to cover situations when a long queue may be present, even though desirable queue management may target shorter queue lengths.

The signs for wide ramps are generally installed on gantries but cantilever structures may be used if appropriate. Other bridge structures over the ramp may also be used only if they are in suitable locations.

Sign location design may also consider the vehicle detector locations to make use of the gantry structure for wireless detector repeater or access points and power or communications connections.

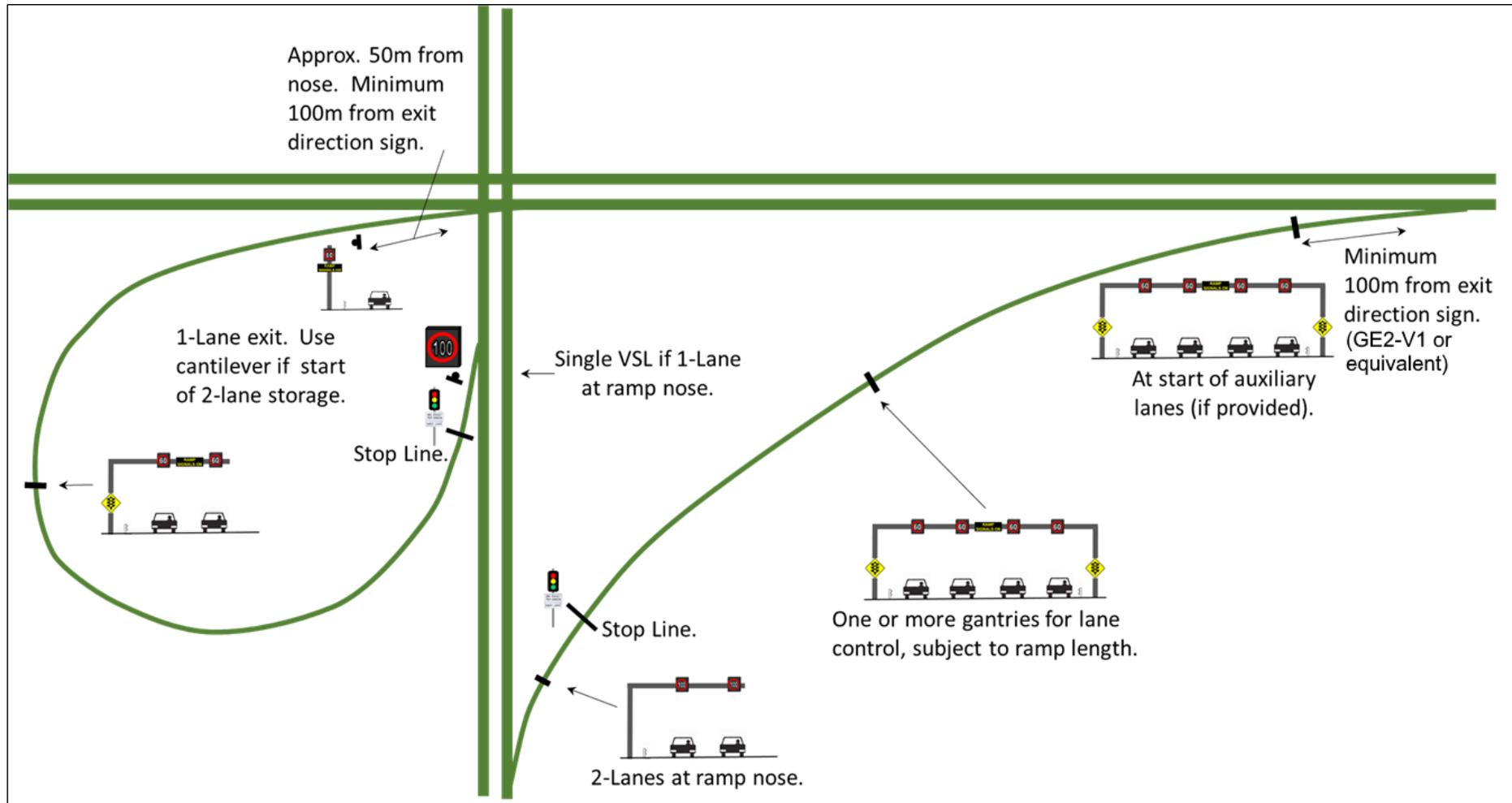


Figure 7-8: Typical Locations for RC2-C and Lane Control Signs (Single Direction Ramps)

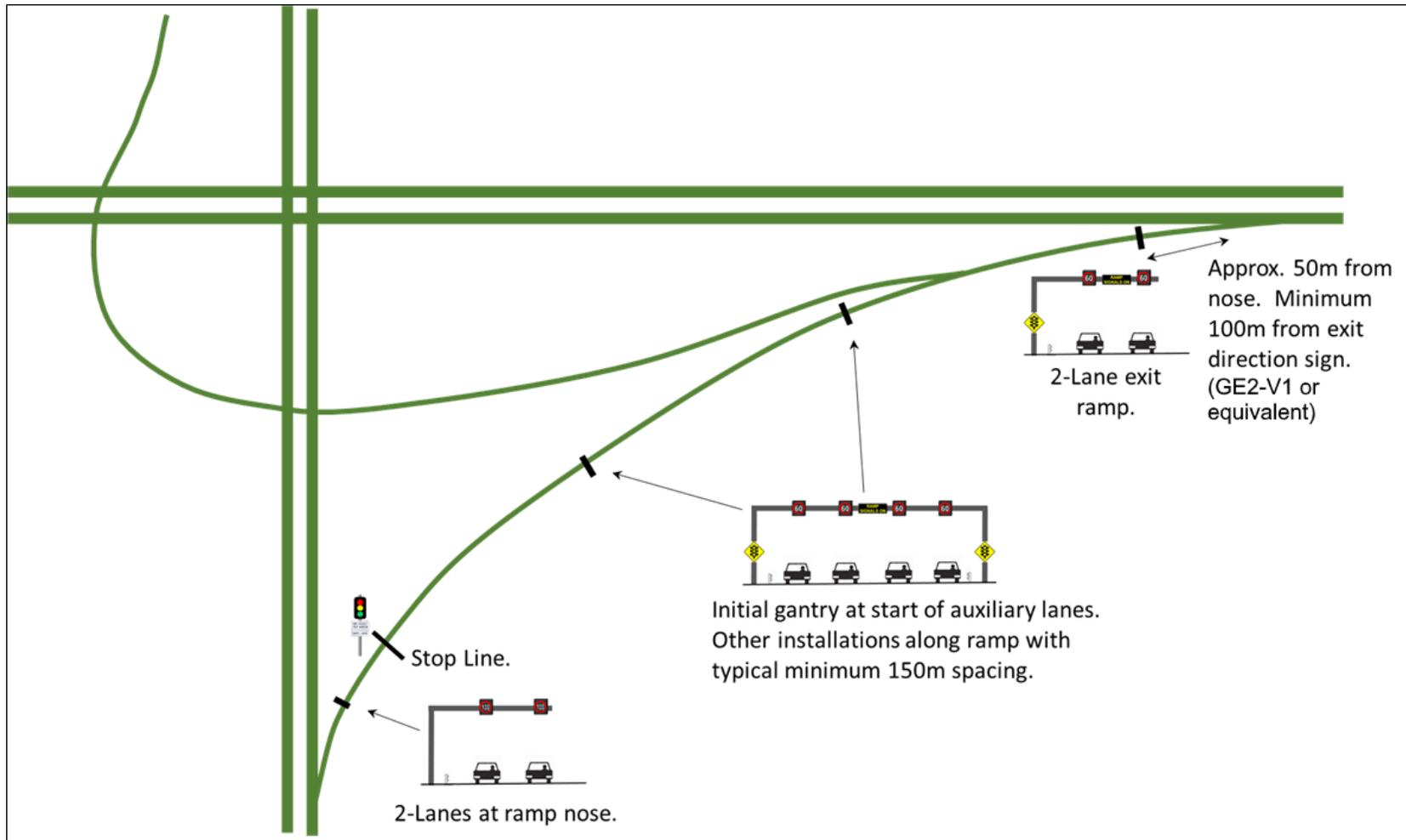


Figure 7-9: Typical Locations for RC2-C and Lane Control Signs (Ramp Bifurcation)

7.5 Speed and Lane Management

7.5.1 Speed Management

The operation of ramp signals on a motorway-to-motorway ramp generally requires speed management using variable speed limit (VSL) signs on the ramp. Overhead lane control and/or VSL signs and RC2-C signs are co-located to provide related warning and speed/lane use information.

VSL signs are generally C Size (900 x 900mm) due to the importance of the sign and to suit the likely traffic speeds on high standard motorway-to-motorway ramps.

7.5.2 Ramp Speed Limits

7.5.2.1 Ramp Signals On

When the ramp signals are operating the controlled ramp speed limit would generally be 60 km/h.

On a long ramp where calculated storage or actual queues are significantly shorter than the ramp length, a buffer speed limit from the motorway being left and the operating speed may be appropriate within the ramp, e.g. stepping down from 100km/h to 80 km/h then 60 km/h, may be considered.

For shorter ramps, the same speed limit would operate for the full length of the ramp, i.e. the same value at all sign locations (ramp signals on or off). Therefore, the speed limit entering the ramp would generally reduce from 100 km/h to 60 km/h beyond the exit ramp nose without a buffer speed limit. In the event of long queues a warning message can be provided on the RC3-C (refer Section 7.6).

7.5.2.2 Ramp Signals Off

When the ramp signals are off the displayed speed limit (default operation) shall be appropriate to the ramp design geometry. The speed limit would typically be 80 km/h but may also be up to 100 km/h for ramps with appropriate geometry.

7.5.2.3 Speed Limit Downstream of the Stop Line

The speed limit signs downstream of the ramp signals (static or VSL) need to match the speed limit of the motorway the ramp is entering.

7.5.3 Overhead Lane Control

The overhead lane control signs enable management of all lanes across the ramp when the ramp signals are operating as well as when they are not in use. This provides operational flexibility as well as positive traffic management and safety.

When ramp signals are operating the overhead lane control signs indicate the ramp metering speed limit for all lanes. When ramp signals are off, the default speed limit is displayed on all lanes, including extended auxiliary storage lanes if the ramp geometry is designed for merging and operating at that speed, i.e. the VSL signs will be on for all lanes displaying the speed limit appropriate to the operating state at that time. Typical layouts are shown in Figure 7-10 and Figure 7-11.

For ramps where overhead VSL is required, overhead lane control (LUMS signs) should be provided rather than dedicated VSL signs, as this enables closure of lanes for incident management on the ramp as appropriate.

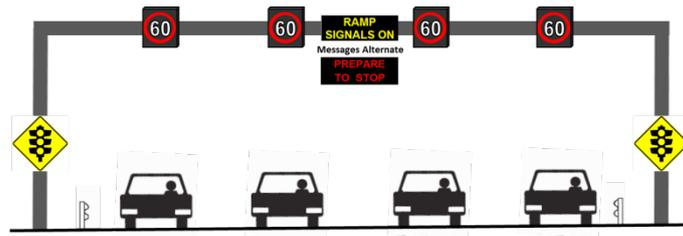


Figure 7-10: Lane Control Signs for Multi-lane Storage – Ramp Signals On

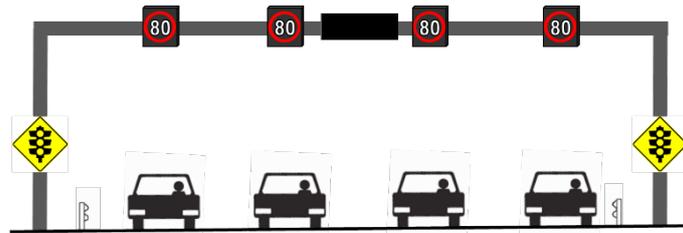


Figure 7-11: Lane Control Signs for Multi-lane Ramps – Ramp Signals Off

For one lane or two lane ramps (localised flaring may be used to provide short auxiliary lanes at the stop line), side mounted VSL signs may be provided or LUMS signs may be mounted overhead for consistency with other ramps.

When the ramp signals are either on or off and lane use is to be managed for an incident or maintenance works, a red cross may be displayed on LUMS signs to close lanes. This would enable all lanes across the ramp, including auxiliary lanes, to be managed according to the event conditions. On a long ramp with multiple overhead sign locations, display of other LUMS symbols should be generally consistent with the rules and principles outlined in Managed Freeways Handbook for Lane Use Management, Variable Speed Limits and Traveller Information (VicRoads, 2013).

7.5.4 Sign Locations and Installation – Upstream of Stop Line

Design guidance and typical sign arrangements for installation along the ramp are provided in Section 7.4.2 and in Figure 7-8 and Figure 7-9.

7.5.5 Sign Locations and Installation – Downstream of Stop Line

Speed limit signs are provided between the ramp signals stop line and the ramp nose to indicate the speed limit on the motorway that the traffic is entering. Where the ramp is a single lane at the ramp nose, a single sign may be side mounted on the left side of the ramp, or on the right side if needed for improved visibility, e.g. on a loop ramp. Where the ramp is two or more lanes at the ramp nose, signs are required on both sides of the ramp.

Where the ramp is entering a LUMS or VSL mainline environment, overhead lane control or VSL signs (overhead or side-mounted) are provided. Otherwise static speed limit signs matching the speed limit of the downstream motorway are used.

For ramps with two or more lanes at the nose, the use of overhead lane control signs on a cantilever (or gantry) is preferred (refer Figure 7-12), particularly for ramps with lane control signs along its length upstream of the Stop Line. This facilitates the potential for lane control to be implemented when necessary, e.g. if a lane is closed on the ramp, the lane can be reopened prior to the nose, or alternatively, if an incident occurs in the vicinity of the ramp nose, then a lane can be closed at this point.

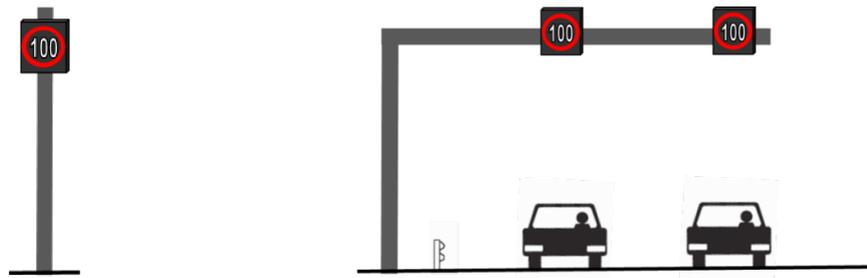


Figure 7-12: VSL / Lane Control Signs Downstream of Stop Line (1-Lane and 2-Lanes at Nose)

7.6 Mainline RC3-C Warning Signs

7.6.1 Purpose and Functionality

An RC3-C VMS is a dynamic warning sign installed on the upstream motorway mainline prior to the interchange with ramp metered connections to provide warning to exiting motorists that the ramp signals on the ramp connection are operating as well as an indication of downstream traffic conditions (colour coded).

The RC3-C VMS also has the capability to provide other traveller information relating to operation of the ramp and to assist in network optimisation and management, e.g. during incidents, lane or ramp closures, roadworks, etc. The RC3-C sign default display when ramp signals are off is blank unless needed for incident or congestion management.

The sign header (first line) is colour coded according to traffic condition thresholds for Light (green), Medium (yellow), Heavy (red), Major Delays (Red) and Seek Alt Route (Red) as outlined in Section 4.2.2 of the Managed Freeways Handbook for Lane Use Management, Variable Speed Limits and Traveller Information. Further information may be provided in the future relating to particular traffic situations (not intended for display when first installed).

The two-fold purpose of the escalating messages during congested conditions is to provide general advice to motorists and to deliver information that could lead to diversion of traffic to other routes if this is feasible.

7.6.2 Sign Displays

7.6.2.1 Displays for Single-Direction Exit Ramp

When ramp signals are on (refer typical displays in Figure 7-13):

- The first line of the sign (header line) is colour coded to match traffic conditions on the motorway being entered in accordance with the principles and traffic condition thresholds in the Managed Freeways Handbook for Lane Use Management, Variable Speed Limits and Traveller Information (2013).
- The bottom line will indicate 'Ramp Signals On'.



Figure 7-13: Typical 'Ramp Signals On' displays – single direction ramp

7.6.2.2 Displays for Two-Direction Exit Ramps

If the exit ramp divides for travel in two directions after the mainline exit, the following rules are applied to the sign messages (refer typical displays in Figure 7-14).

- If ramp signals are on for only one direction, display the information for that direction;
- If ramp signals are on for both directions of travel indicate both directions of travel.



Figure 7-14: Typical 'Ramp Signals On' displays – two-direction ramp

7.6.2.3 Displays for Priority Traffic Situations

The principal focus for RC3-C messages is the traffic condition on the controlled ramp, rather than traffic conditions for the downstream section of motorway.

When there is an incident, maintenance or congestion on a controlled ramp, the following messages display on the RC3-C warning signs within the following signage hierarchy of priorities:

1. Ramp Closed
2. Incident on Ramp
3. Roadwork on Ramp
4. Long Queues
5. Ramp Signals On

The operational principles for display of these messages are:

- For the affected direction of travel, the colour-coded header line is displayed, whether the ramp signals are operating or not operating.
- The priority message is displayed on the bottom line of the RC3-C sign in yellow (or red for 'Ramp Closed').
- If the ramp signals are on, the priority message overrides the 'Ramp Signals On' message and any other lower priority message, e.g. a 'Roadwork on Ramp' message overrides a 'Long Queue' message.
- Information (header line and colour coded traffic condition) will not be displayed for a ramp if the ramp signals are not active (refer to Section 7.6.2.2).
- If both ramps are requesting the same message, then both ramp headers are provided at the top with the common message displayed at the bottom line. If the ramps are requesting different messages, the ramp with the higher priority message will be displayed.

Typical displays are shown in Figure 7-15.

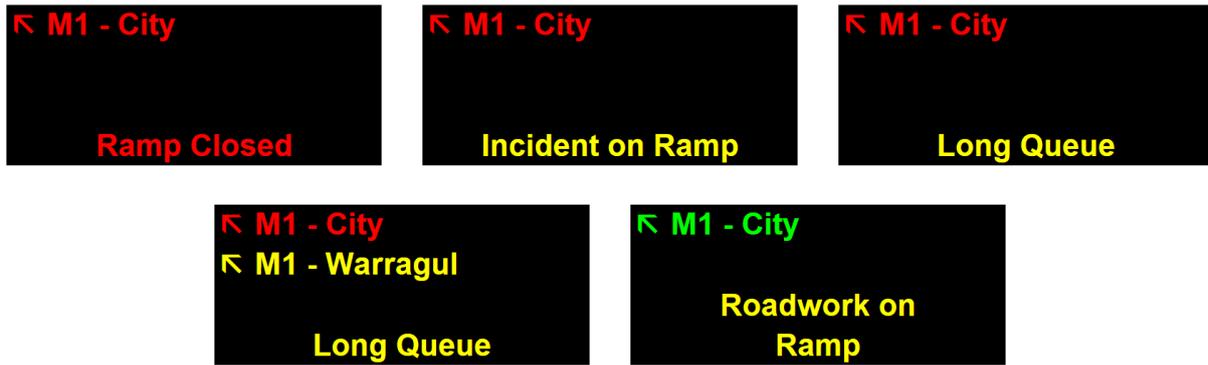


Figure 7-15: Typical RC3-C priority traffic situation displays

7.6.3 Sign Locations

Location of VMS prior to an exit can be challenging due to the spacing requirements relative to other signs and the exiting lane arrangements, particularly with multi-lane exits. Generally, the positioning of exit direction signs and VSL/LUM signs takes priority over the location of VMS.

To avoid signing complexity and to maximise opportunity for motorists to absorb information, the preferred installation of the RC3-C prior to a motorway exit is at a separate location relative to other signs. However, in some instances flexibility is needed due to design constraints and the VMS may need to be co-located with LUM signs or direction signs due to design constraints.

The position of RC3-C prior to the exit shall be in accordance with the following general design principles:

- The preferred RC3-C location is separated from other signs as shown in Figure 7-16 and Figure 7-19.
- The sign would generally be installed about mid-way between the 1km and 500m advance exit direction signs, with a desirable minimum separation distance from other signs of 200m. This position relates the RC3-C traffic information message to the direction sign exit information and generally would also provide sufficient distance for motorists to read the sign and make a decision for a range of exit arrangements.
- For a longer exit lane arrangement, e.g. a long single exclusive exit lane or a two-lane exit, the RC3-C should be positioned after the initial advance exit direction sign and desirably prior to the start of the exit lanes, with a general maximum of 1200m prior to the related motorway exit. If there are design constraints, e.g. curves and/or high concentration of lane changing manoeuvres where motorist distraction is to be avoided, then the sign may need to be positioned after the commencement of the exit lanes.
- As the sign is intended for exiting traffic, the VMS should be installed near the left side of the carriageway typically over the emergency stopping lane (preferred) or over the left lane for a 2-lane exit. This position reinforces the purpose of the message for exiting traffic compared to the centrally mounted mainline VMS for the continuing route.

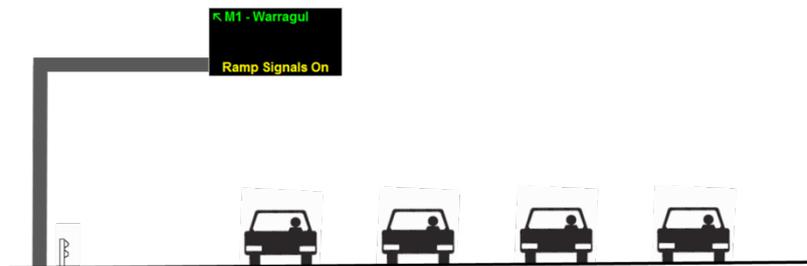


Figure 7-16: RC3-C Separate installation (Preferred)

- For exits where design constraints prevent separate installation, the RC3-C may be co-located with:
 - LUM signs as shown in Figure 7-17 (preferred), or
 - A simple advance exit sign, e.g. an ‘Exit 1km’ or ‘Exit left Lane’ direction sign as shown in Figure 7-18. It would generally be undesirable to co-locate the RC3-C with complex signage, e.g. lane allocation signs or exit signs with more than one destination.

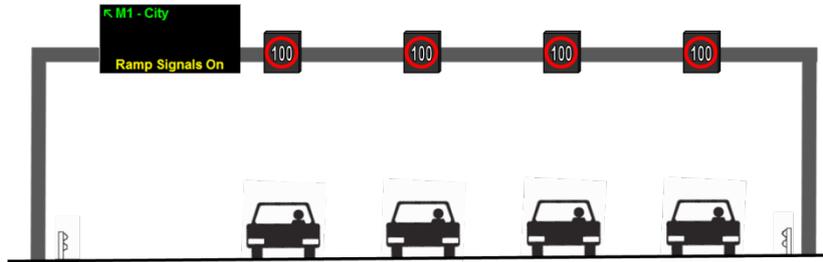


Figure 7-17: RC3-C co-located with LUMS (separation not feasible)

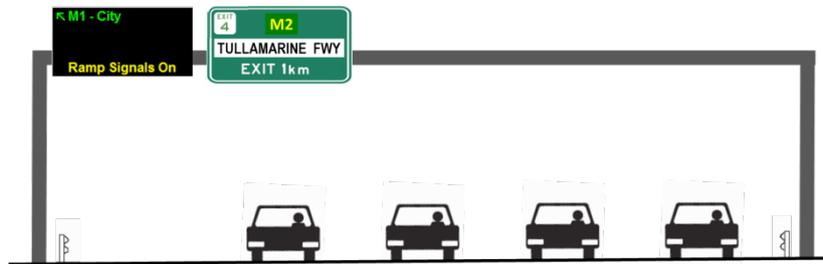


Figure 7-18: RC3-C co-located with Advance Direction Sign (separation not feasible)

7.6.4 Sign Structure

Subject to structural, maintenance and other considerations, the RC3-C would generally require an accessible cantilever (refer Figure 7-19) or gantry structure.



Figure 7-19: RC3-C Installed on Cantilever Structure

7.7 Vehicle Detection

7.7.1 General Principles

The availability of good quality traffic data (speed, flow and occupancy) is crucial to effective operation of the ramp signal system and management of queues on the ramps. Vehicle detectors are provided in locations on the mainline and ramps where data is required for system operation.

7.7.2 Mainline Detectors

The mainline detector stations used for minimising flow breakdown and optimising the system are provided in accordance with Chapter 5.

7.7.3 Entry Ramp Detectors

The entry ramp detector locations shall be consistent with the principles in Section 6.10.4 to suit operation for calculation of queue lengths and to manage queues and waiting time on the ramp. This includes stop line, middle of the ramp and entry to the ramp according to the following principles:

- Three (3) sets of detectors on ramps generally meeting (or less than) desirable storage as shown diagrammatically in Figure 7-20. The ramp entrance detectors are used for queue management and to manage queue override activation to prevent interference of the ramp queue with the upstream adjoining motorway.
- Four (4) sets of detectors for ramps significantly longer than the desirable minimum 4 minutes of storage, as shown diagrammatically in Figure 7-21. On a long ramp, the ramp entrance detectors are located at the calculated desirable storage distance (4 minutes) from the stop line. Queue overflow detectors are then provided on the ramp near the ramp nose near the upstream adjoining motorway.
- Four (4) sets of detectors for ramps where ramps branch for travel in two directions, as shown diagrammatically in Figure 7-21.

The detectors are provided in all lanes at each detector station (two per lane). The gantries or separate poles are used for the wireless repeater and access points.

Additional ramp detectors for redundancy (in case of faults) are generally not provided but may be considered if operational issues indicate there could be significant operational or safety risks associated with queues if a failure did occur.

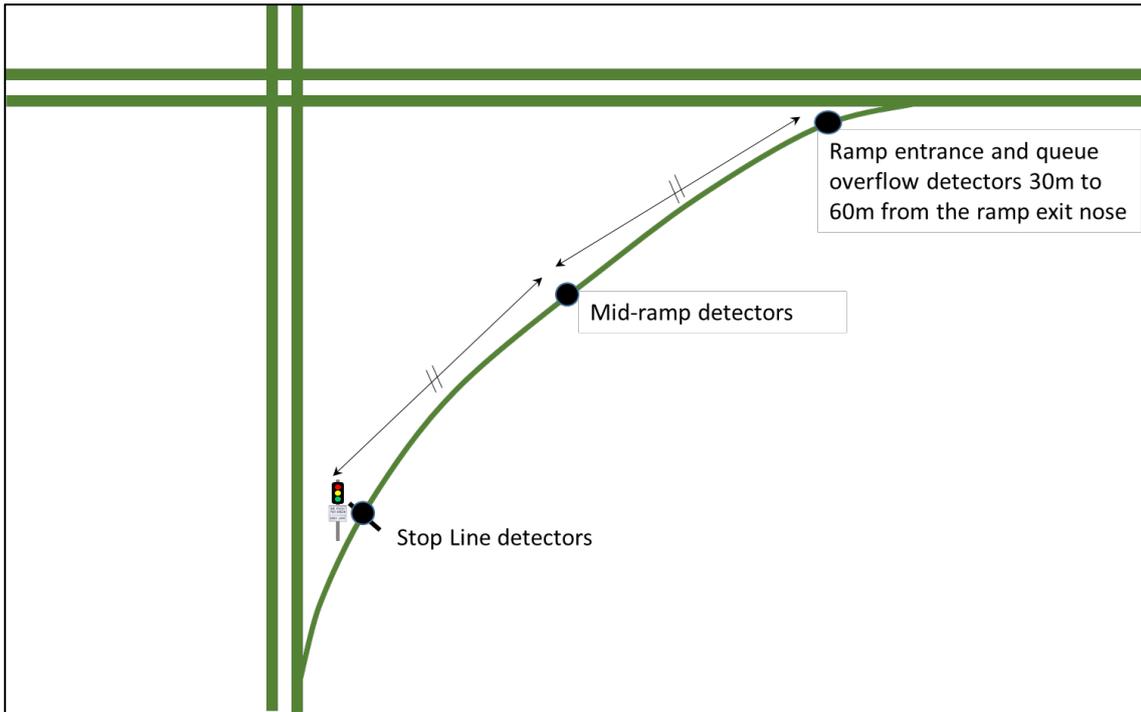


Figure 7-20: Typical Ramp Detector Locations

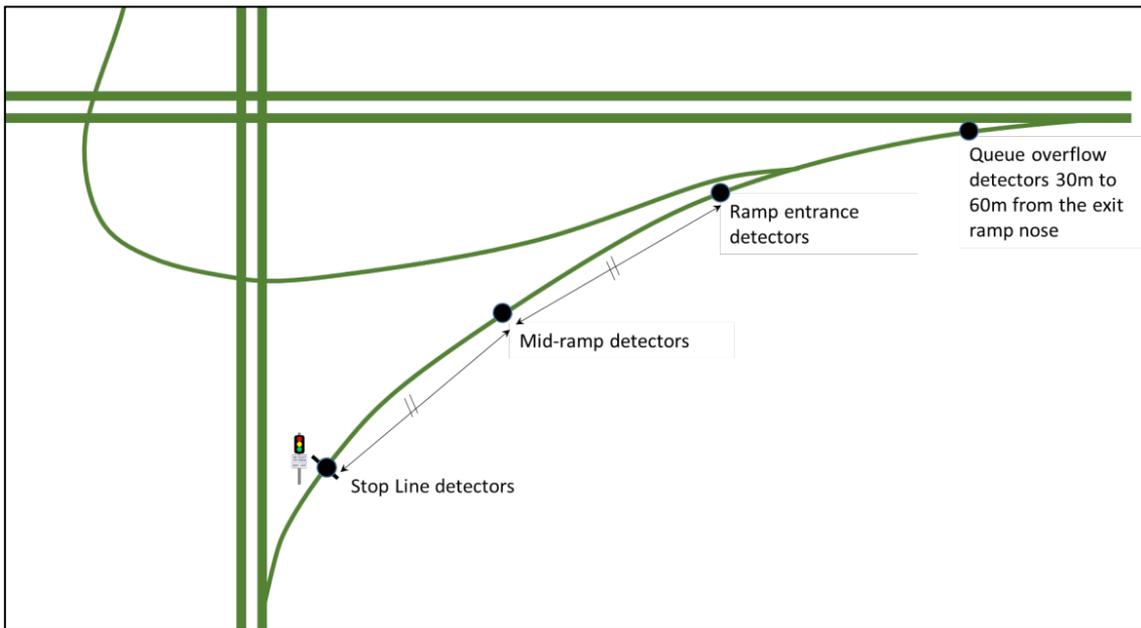


Figure 7-21: Typical Ramp Detector Locations (Long Ramp)

7.8 Other Signs

Other signs for ramp signal installations on motorway-to-motorway ramps are generally provided in accordance with Section 6.10.9.

7.9 Pavement Markings

7.9.1 General

Pavement markings for the stop line, lane lines and edge lines at ramp signal installations on motorway-to-motorway ramps are generally in accordance with Section 6.10.10.

7.9.2 Extended Auxiliary Storage Lanes

On ramps where extended auxiliary lanes are provided at the stop line for storage or to minimise the overall length of queues, the lane line separating the auxiliary storage lanes from the general traffic lanes shall be a 9m line with 3m gap to discourage their use when the ramp signals are not in operation.

7.10 CCTV Cameras

In addition to the CCTV camera coverage requirements outlined in Section 6.10.11, at motorway to motorway interchanges coverage also needs to include the ramp diverge / exit from the upstream motorway.

In view of the critical nature of motorway-to-motorway ramp operations, it is desirable to have overlapping coverage in case of camera faults or incidents (i.e. 200% coverage). For long ramps, two or more cameras may be necessary.

Where the controlled ramp is at an interchange which is the junction of motorways under different agency responsibility, e.g. VicRoads and a toll road operator, the CCTV cameras provided for the ramp signals monitoring and operations (including coverage of the design ramp storage area) shall be connected to and controlled by the VicRoads system. Sharing of additional cameras may be considered if appropriate operational protocols are in place.

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Chapter 8: Surface Road Access Management



8 Surface Road Access Management

8.1 General Principles

Volume 2, Part 2 outlines the principles associated with the integration of managed motorways with the surface road network to achieve an effective motorway / surface road interface. This includes the operation of the intersection itself as well as the resulting operation of entry ramps and exit ramps connecting to the motorway.

The general principle for operations on the road network as whole, is that if the motorway is able to carry more traffic in the peak periods, it follows that the operation of surface roads will also be more efficient, compared to a situation where motorways are poorly unmanaged. This generally implies that managing the entry and exit ramp flows for the benefit of the motorway operation needs to be given a high priority.

8.2 Interchange Capacity and Design Performance

Interchange layout and capacity need to be able to manage traffic into and from the motorway in an efficient manner to minimise delays and to ensure that this connection to the road network does not adversely impact the overall motorway operation, nor the operation of traffic along the surface road. Austroads Guide to Traffic Management (AGTM) Part 6 – Intersections, Interchanges and Crossing (Austroads, 2017) and associated VicRoads supplements provide guidance for interchange and intersection selection and analysis. Layout selections need to also consider the dynamic traffic conditions that can be associated with ramp metering operations.

Capacity analysis shall be carried out at interchanges based on design volumes (AM and PM peak) to evaluate the degree of saturation at the interchange and the queue lengths, particularly storage needed for turning lanes.

The desirable design standards include:

- Practical degree of saturation not greater than values required in Austroads guidelines, i.e.
 - 0.90 - for signals
 - 0.85 - for roundabouts
 - 0.80 - for Stop or Give Way sign control
- Right turn and left turn lanes to accommodate 95th percentile queues, in addition to required geometry for deceleration.

8.3 Managing Entry Ramp Queue Overflows

8.3.1 Potential Ramp Problems

In managing motorway access, the principal consideration is preventing flow breakdown on the motorway and optimising efficiency (travel time and throughput). Therefore, the motorway capacity and stability are the main factors determining the ramp entry flows, rather than the traffic demands on the ramps themselves. Whilst this philosophy generally transfers operational delays from the motorway to the entry ramps, the delays for the road network as a whole, including the motorway, are reduced relative to operating a congested motorway under equivalent demand flows.

8.3.2 Operational Principles

Ramps should be designed to accommodate queues as described in Section 6.3. The ramp queues should then be managed within the ramp length. However, at locations where assessment indicates that high entry ramp demands cannot be satisfied, i.e. it may not always be feasible to increase ramp storage and traffic queues that extend onto the surface road network could be experienced. In other (generally rare) cases, it may be more economical to provide for storage along the surface road rather

than extend/modify the motorway ramp. (Refer to Section 6.3 for design principles and further requirements.) In this situation the additional, dedicated storage should be provided primarily to avoid interference with other surface road flows for through traffic. This additional, dedicated storage should not be used in calculating the overall ramp or system storage for dynamic operations since the free progression of traffic from such storage may not be guaranteed or facilitated by the ramp metering system.

During real time operation, the various queue management algorithms in the HERO suite of algorithms, and particularly the queue control and override modules, enable the ramp entrance / surface road interface to be managed. In the event that the ramp queue will exceed the available ramp storage, a pre-specified ramp discharge flow can be activated to increase the metering rate. This entry ramp discharge flow value shall be determined to avoid an excessive inflow of traffic to the mainline that may trigger flow breakdown, which can also increase the crash risk. Letting the motorway flow collapse usually results in excessive queueing, including queues extending back into the ramps and potentially the surface road.

Preventing mainline flow breakdown is the prime operating objective in relation to the interchange management. Maintaining non-breakdown mainline flows also results in improved entry ramp flows being able to enter the motorway. Although the system has a number of settings to increase ramp flows due to queuing or waiting time, it may not always prevent queuing onto the surface road. Mainline flow problems may not occur in the immediate vicinity of an entry ramp, being just as likely to occur further downstream (possibly out of sight). 'Flushing' or 'dumping' of traffic from an entry ramp using high ramp discharge flows to overcome surface road queues or delays can therefore be an inappropriate operational strategy from a whole of network perspective. Permitted flows coded into the system relating to queue control, queue override and waiting time need to be determined appropriately to avoid / limit the impacts of mainline flow breakdown, both locally and remote from the ramp influence area.

During design where queues are expected to extend onto the surface road on a regular basis, the design may need to provide for detection of queues on the surface road and/or include provisions to accommodate queue overflows as outlined in Section 8.3.3.

The evaluation of ramp queue overflow may also need to consider the capabilities of the road network to accommodate trip diversions (refer to Section 6.3.2). Where significant volumes cannot be managed on an existing or proposed entry ramp and/or surface road approach, further consideration may need to be given to a revised layout as part of the iterative design process.

8.3.3 Treatment Strategies and Options

Drivers generally have the ability to adapt to changing motorway accessibility and modify their travel patterns accordingly, i.e. for route choice or time of travel. Therefore, significant physical works should only be considered where route diversions are not feasible or where they have proven to be insufficient.

Real time information signs (RC3) as described in Section 6.10.7.3 are provided in advance of the right and left turn lanes as part of the ramp signal design. Information provided includes travel time and advice regarding incidents and motorway conditions. Where ramp overflows or long delays are expected, motorists may choose to take an alternative route. Other network operational approaches as outlined below for the surface road network need to support the 'one road network' philosophy for the best overall traffic outcomes on the network as a whole.

To manage ramp queue overflow traffic, the following treatment options may need to be considered. It is noted that the implementation of some measures has the potential to worsen queues on the surface road and should only be considered where a demonstrated need exists.

1. Interfacing between the motorway ramp signal system and the SCATS system to initiate specific signal control actions.

2. Treatments to manage the right turn traffic entering the ramp include:
 - Implementation of leading and lagging right turn phases at the intersection to reduce the potential for overfilling of a short ramp, i.e. two short right turn phases within the cycle rather than a single longer phase.
 - Modify the right turn signal phase times to restrict traffic entry.
 - Skip the right turn phase during affected times.
 - Extend the storage for right turning traffic. This could involve extending the turn lane(s) or providing double turning lanes, as appropriate.
3. Treatments to manage the left turning traffic entering the ramp include:
 - Providing or extending left turn lane storage along with appropriate queue detection to ensure queued traffic is clear of through traffic lanes and monitored to enable adjustment to operations;
 - Ensuring appropriate equity between the left and right turning demands:
 - Provision of signals on a left turn slip lane to provide equity between left and right turn movements into the ramp. This treatment is more likely to be needed if there is an imbalance between the left and right turn flows, a high left turn volume or with a single configuration left turn entry (refer Section 6.10.4.3). Left turning traffic accessing an entry ramp via a slip lane can continuously fill the available storage space, preventing right turn access during limited green time with each signal phase.
 - Restricting left turn overlap times.
 - Installing a red left turn arrow.
4. Modify the phase times at other surface road intersections to provide for traffic diversions.

8.3.4 Mitigating Failure of Intersection Traffic Signals

In the event that traffic signals at a ramp terminal intersection experience a failure (black-out or flashing yellow condition), traffic may be able to access ramps in an uncontrolled manner. In the event that a ramp closure is active during a failure, traffic may be able to access restricted or unsafe conditions without warning or control.

To mitigate the potential impacts of loss of power and/or communications to traffic signals that would result in the loss of traffic signal control, Uninterruptable Power Supply (UPS) and the fall-back ability to communicate with traffic signal controllers over wireless communications shall be provided at intersection traffic signals providing access to high risk locations, including entry ramps into tunnels.

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Chapter 9: Exit Ramp Design and Management



9 Exit Ramp Design and Management

9.1 Principles for Managing Traffic at Exit Ramps

Volume 2, Part 2 and Chapter 8 outline the principles associated with the integration of managed motorways with the surface road network to achieve an effective motorway / surface road interface. The objective indicates that:

'... when necessary, the freeway network is to be given priority over the arterial road network and, where this would result in a negative impact on the arterial network, this should be managed accordingly to provide a net overall gain to the system's users.'

Volume 2, Part 2 provides further background relating to the significant role and importance of motorways in the operation of the total road network for best overall arterial road outcomes.

The principle is that if the motorway is able to carry more traffic in the peak periods, it follows that the operation of surface roads will also be more efficient, compared to a situation where motorways are poorly managed. Therefore, this generally implies that managing the exit ramp flows for the benefit of the motorway operation needs to be given priority over the arterial road.

In this section, managing traffic where a motorway terminates at a surface road, especially at an at-grade intersection, has many similarities with interchange exit ramps and many of the considerations discussed are likely to be applicable. Traffic flows are likely to be significantly higher than typical exit ramps and specific considerations may be required.

9.1.1 Design Standards

The provision of appropriate design standards at exit ramps can assist in minimising mainline turbulence and safety concerns. The width of exit ramps at the ramp nose and adequate distance being provided for lane changing on the mainline also needs to service the exiting design volume (refer to Section 3.7.3).

The length of exit ramps needs to service the traffic and capacity needs and interchange operation. Generally, the provision of short exit ramps should be avoided (even for low volume exit ramps), as this can cause a speed reduction in the taper and immediately after the exit gore, and in some cases, could impact the mainline traffic if traffic slows down prior to leaving the mainline through lanes.

The geometric standards for the freeway exit ramp layouts should be in accordance with the VicRoads Supplement to the Austroads Guide to Road Design: Part 4C – Interchanges (VicRoads, 2010).

9.1.2 Potential Mainline Problems

Traffic flow on the motorway mainline is affected when traffic queues on an exit ramp extend back to block the left lane of the motorway as shown in Figure 9-1, or cause traffic to slow down prior to exiting. This may cause:

- Flow breakdown on the mainline under certain conditions
- Significant safety concerns due to high speed differentials between exiting traffic and through traffic on the mainline.

As indicated in Volume 2, Part 2, ramp metering of upstream entry ramps has limited effectiveness in addressing this problem.

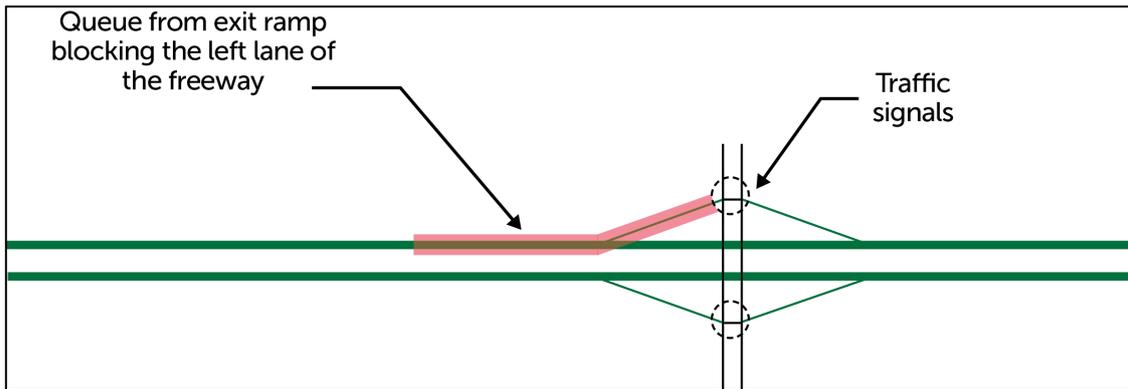


Figure 9-1: Exit Ramp Queue Affecting Freeway Flow

The problem of exiting vehicles causing flow problems on the motorway mainline may be a result of:

- Inadequate capacity of the mainline exit ramp layout. Guidance relating to traffic volume thresholds for various layouts are provided in Section 4.3.2.13.
- Inadequate ramp capacity to handle high exiting flows, e.g.
 - A short ramp with insufficient length between the ramp terminal intersection and the mainline to accommodate queues from the interchange.
 - Insufficient width to enable the ramp to accommodate the exit flow and queues at the interchange.
- Inadequate intersection capacity at the surface road intersection, e.g.
 - Inadequate lane capacity on the ramp approach to the intersection, e.g. insufficient number of lanes or length of turning lanes extending back from the intersection.
 - Inadequate lane capacity on the surface road approaches to the intersection which limit the time that can be allocated to the exit ramp, e.g. insufficient number of through or turning lanes.
 - Stop or Give Way signs at the ramp exit.
 - A roundabout interchange with inadequate capacity or unbalanced flows.
- Inappropriate signal phasing and/or timings. The SCATS stop line detectors are able to determine if queues have not been satisfied at the end of a phase, but the SCATS system does not generally detect the length of the queue.
- Traffic flow or capacity problems on the surface road downstream of the interchange that may restrict traffic departing the intersection.

The safety of traffic related to exiting the motorway and the impact on capacity are important operational concerns. Potential problems need to be addressed to prevent delay and road users' exposure to increased risk on account of poor exit conditions.

The objective and principles of giving motorway operation priority over the surface road network implies that the exit ramp flows should have priority over the entry ramp flows as the exit ramp flows can cause significant congestion on the freeway mainline, e.g. flow breakdown on a four lane freeway carriageway could affect a freeway flow of up to 8,000veh/h over a distance of many kilometres and for the balance of the peak period. Therefore, getting traffic off the freeway should be seen as the highest priority with other movements being given lesser priority in the majority of cases.

9.1.3 Mitigating Failure of Intersection Traffic Signals

In the event that traffic signals at a ramp terminal intersection experience a failure (black-out or flashing yellow condition), queues on exit ramps may be significantly impacted and result in queues extending onto the upstream motorway carriageway, creating potentially unsafe conditions as described above.

To mitigate the potential impacts of loss of power and/or communications to traffic signals that would result in the loss of traffic signal control, Uninterruptable Power Supply (UPS) and the fall-back ability

to communicate with traffic signal controllers over wireless communications shall be provided at intersection traffic signals at locations identified as high risk including:

- Sites that facilitate exit ramps from tunnels
- Sites that facilitate end-of-motorway connections with surface roads
- Other sites that may pose a high risk to motorway mainline flows in the event of traffic signal failure due to high exiting flows and intersection conditions that are likely to significantly impede progression of priority controlled traffic flow from an exit ramp.

Further consideration should also be given to providing UPS at nearby signalised intersections that also facilitate the clearance of traffic away from the high risk locations outlined above.

9.2 Treatment Options

Traffic that is leaving a freeway needs to be managed to reduce the likelihood of exiting traffic interfering with mainline freeway traffic flow. The following actions may need to be considered, as appropriate, to address this problem:

1. Modify the surface road traffic signal phase settings to facilitate a general increase in exit ramp traffic discharge.
2. Modify the surface road traffic signal phasing to provide an exit ramp phase extension or other changes in traffic signal operations to increase queue discharge when the ramp queue is long. A queue length estimate would be determined by the provision of exit ramp detectors (refer Section 9.4) feeding relevant information to queue estimation software within the managed motorway control system with an interface to the SCATS traffic signal system. As queues grow on the exit ramp, traffic signal operations should increase the priority in clearing ramp queues.
3. Increase the intersection capacity by providing:
 - Additional lanes on the exit ramp approaching the intersection to facilitate the discharge of more traffic within the available phase time. This may include additional right turning lanes, left turning lanes or a left turn slip lane at the signals.
 - Additional lanes for through and/or turning traffic on the surface road at the traffic signals. This can reduce overall delays and enable reallocation of time to the exit ramp signal phase.
 - If the intersection is not signalised, replace Stop or Give Way control with new traffic signals to facilitate the discharge of exiting traffic.
4. Where a roundabout is provided at the surface road intersection, provide roundabout metering signals to facilitate exit ramp egress.
5. Considering downstream improvements on the surface road to enable traffic to clear the intersection, e.g. signal linking or capacity improvements.
6. Increase the ramp length to accommodate longer queues.
7. Increase the number of lanes exiting from the motorway mainline and/or along the ramp for more queue storage and/or to provide more efficient access to turn lanes at the ramp terminal intersection.
8. Providing a longer marked exit lane (preferred), or allowing exiting vehicles to queue on the emergency stopping lane. Dynamic queue-activated signing may need to be provided or static signs permitting the use of the shoulder at appropriate times.

9.3 Exit Ramps Design Storage

Capacity analysis shall be carried out at the interchange based on design volumes (AM and PM peak due to varying demands) to evaluate the degree of saturation at the interchange and the queue lengths, particularly storage needed for turning lanes. The standards for interchange / ramp terminal intersection design and capacity, which incorporate exit ramp operations, are provided in Section 8.2.

The provision of adequate exit ramp storage for motorway exit ramps is necessary to avoid the problems of exit ramp queues extending back and interfering with mainline traffic flow.

9.3.1 Motorways with Tunnel Sections

Minimising the need for lane changing increases the inherent safety of a tunnel. Therefore exit ramps that require significant diverging and lane changing are undesirable within a tunnel or close to a tunnel portal. With some entry and exit configurations (subject to origins and destinations), vehicles may also need to change lanes several times in order to be in a position to diverge.

Exit ramps in the proximity of a tunnel may also create a risk to the operation of tunnel traffic where the exiting traffic 'backs up' and blocks the exit ramp, and in the worst case, obstructs flows in the tunnel. Minimising the need for diverging and lane changing in a tunnel helps to maintain more consistent vehicle speeds and improves safety. Preferably the diverge taper should not start less than 500m after the tunnel portal.

Where network connections and other physical constraints require ramps and diverges in close proximity (i.e. closer than 500m), or within, tunnel sections, guidance and direction shall be sought from VicRoads subject matter experts or VicRoads' nominated representatives. In such circumstances, the location of ramps and merges and the associated geometric arrangements and technology provisions require approval by VicRoads Road and Traffic Design Department.

Any exit ramps in the proximity of the tunnel portal or within the tunnel environment shall be considered as high risk, as poor design of these interfaces can contribute to dangerous behaviour of drivers and a resulting increase in the risk level and incidents. Design of tunnel and ramp interfaces shall include input from Human Factors specialists with expertise in road tunnel environments to minimise the possibility of late and unexpected actions from drivers near the access points.

It is critical that good visibility of the exits and the legibility of signage is provided to facilitate the required driver behaviour.

Specific treatment options will depend on context (i.e. including approach geometry), but could include unique designs at each access location to assist drivers with orientation and required behaviour at high risk areas. Generally best international practice has considered inclusion of some or all of appropriate illumination, patterns, colour, architectural installations treatments etc. where considered necessary (PIARC Technical Committee 3.3 Road Tunnel Operation, 2016).

Design solutions shall consider best international practice and are required to address risk and context at each access interface with risk mitigation proposals, analysis and decision making clearly documented in Design Reports.

9.4 Exit Ramp Management System

The Exit Ramp Management System (ERMS) integrated into VicRoads Managed Motorway control system operates to manage exit ramp queues in association with the SCATS signal system. While this system operates to interact with the surface road signal system, in the first instance every effort should be made to ensure the interchange design is sufficient to limit the need for the system to intervene.

Where a motorway terminates at a surface road, the ERMS has the flexibility to be utilised to detect and estimate queues that are likely to develop at signalised intersections that manage traffic exiting the motorway. The physical carriageway arrangements are likely to be unique where such terminating conditions exist and placement of detection to facilitate the ERMS will need to consider the localised context and the existing/proposed traffic signal operations. In general, provision of technology and application of ERMS should aim to avoid or limit the impact of queues on other high speed movements in the vicinity of the terminating carriageway (e.g. avoid queues spilling into a upstream location where traffic streams may bifurcate).

9.4.1 Exit Ramp Vehicle Detectors

To facilitate operations, detectors are included on all interchange exit ramps as shown in Figure 9-2. The general principles for placing detectors should also form the basis for treating terminating motorways.

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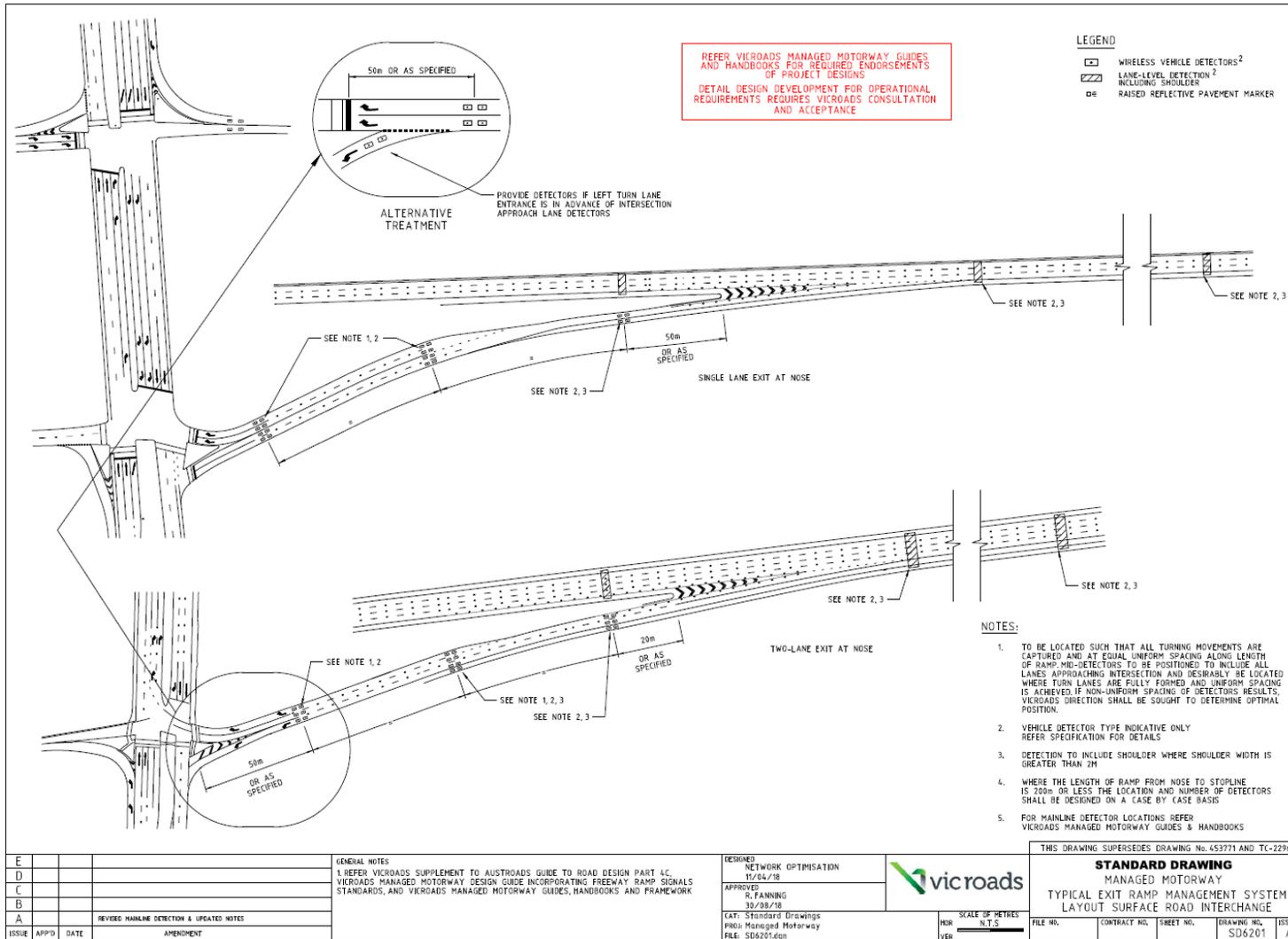


Figure 9-2: Detectors for Exit Ramp Management System

APPENDICES

Appendix A

Extended Design Domain

Extended design domain (EDD) values and practice are outside the normal design domain (NDD) adopted for design by road authorities. These values for geometric road design have been trialled or found to provide suitable solutions in constrained situations, typically at brownfield sites. Further guidance relating to the application of EDD with available criteria is in Austroads Guide to Road Design Part 3: Geometric Design (Appendix A). EDD principles are explained in Austroads Guide to Road Design Parts 1 and 2.

Design values within the realm of the EDD should only be considered for use if appropriate for the prevailing conditions. Proposals using EDD values for managed motorways require approval by VicRoads Roads and Traffic Design Department.

Staggered Stop Line Layout for 3-Lane Ramp Metering Signals

Application:

The use of a staggered stop line layout for a ramp needing 3-lane ramp metering signals as shown in Figure F-1, may need to be considered as a minimum EDD treatment in the following circumstances:

- Where three lanes are needed for discharge capacity.
- Where it is not feasible to provide the typical three lane layout to provide the desirable storage (where the stop line is located 150 metres upstream of the ramp nose and ramp tapers to a single lane at the ramp nose).
- Where the desirable storage is important for management of a downstream bottleneck.
- Where queues extending from the ramp would significantly impact the surface road operations.

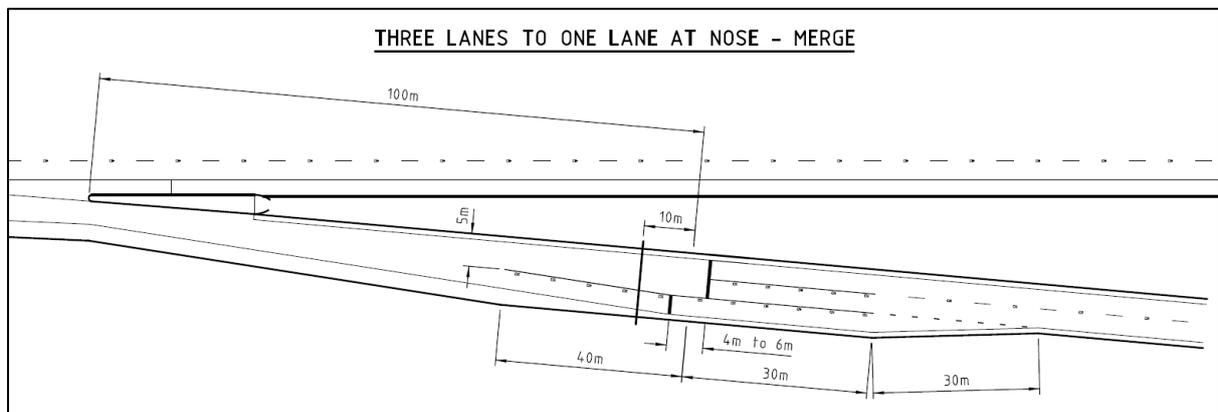


Figure A-1: Staggered Stop Line Layout for 3-lane Ramp Meter

Use of the staggered stop line layout would generally result in the following benefits:

- Achieving an additional 100 m of ramp storage compared to the typical three-lane layout (merging from a flared three lanes to one lane at the nose).
- Facilitating more effective mainline management and improved equity of access for the coordinated ramp metering operations.
- Construction cost savings relative to more extensive works providing the typical layout.

Use of the staggered stop line layout is considered to present a higher risk merge scenario which needs to be recognised during design development and operational application. It is therefore not a preferred solution and shall only be considered where all other preferred options are not viable.

Metered Priority Lane: Option P2

Application:

The Option P2 priority lane layout shown in may need to be used where there is limited distance on the motorway downstream of the ramp nose to accommodate the length for merging or limited ramp length for combined storage and merge distances. As the layout requires a longer distance for merging to one lane prior to the ramp nose (relative to Option P1 in outlined in Section 6.8.2), this means the stop line is located a minimum of 150m from the ramp nose (similar to a normal 3-lane metered layout). This generally reduces the availability of storage on the ramp unless the ramp can be lengthened by extending the nose.

Option P2 is generally undesirable as it relies on an active device(s) to close the lane during unmetered periods, i.e. when the signals are off, and risks an open lane in the event of a device failure or loss of power.

In the Option P2 layout, the priority lane is a part-time lane and not suitable for operation when the metering signals are not operating, i.e. due to the insufficient merge lengths downstream of the stop line for merging at higher operating speeds. The ramp design incorporates overhead lane control signs to designate all lanes and restrict use of the priority lane outside metering times. A separation (generally 0.7m) is provided between the priority lane and the metered vehicle lane. This separation tapers to a single line over the initial 70m merge distance.

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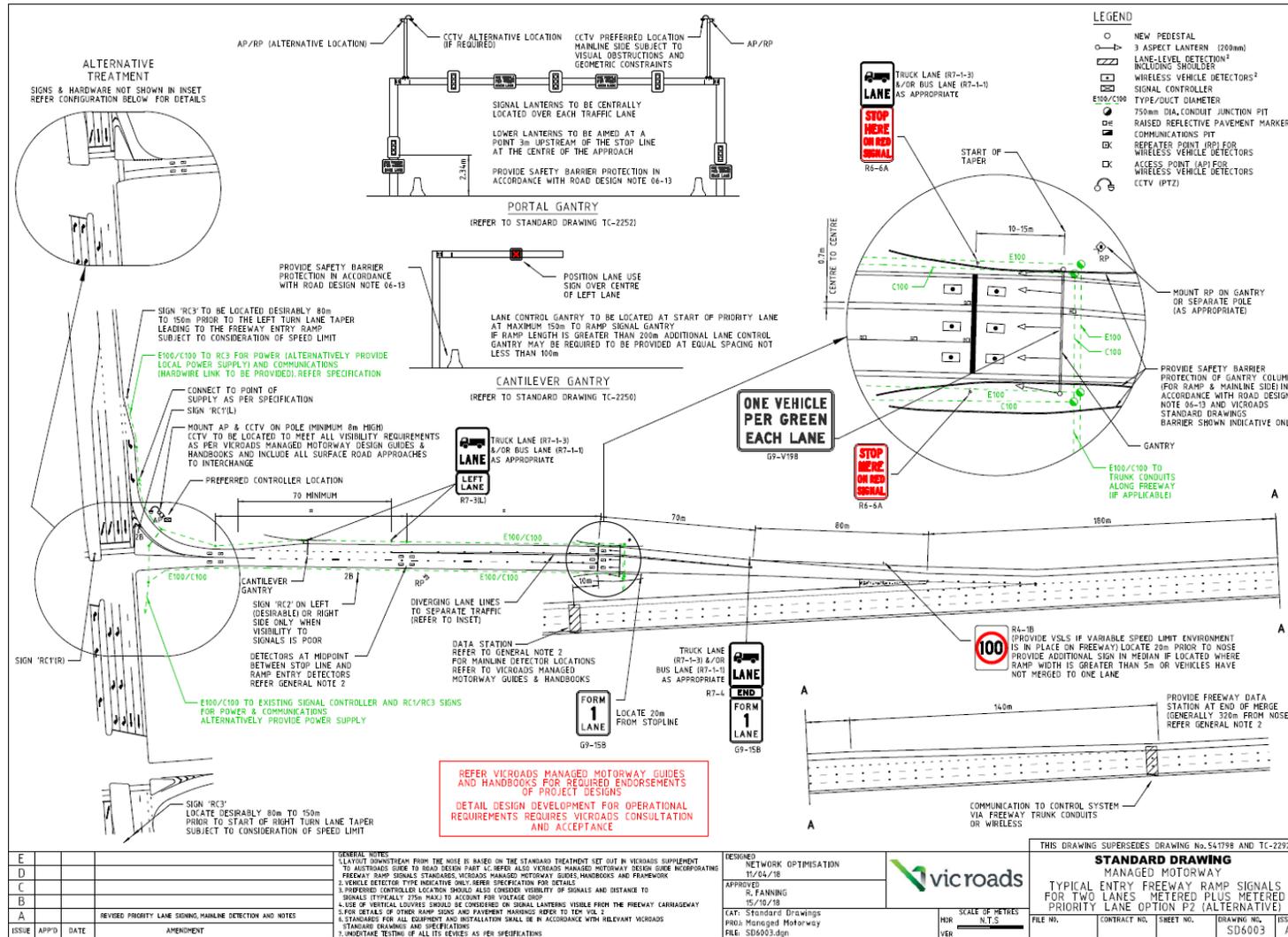


Figure A-2: Metered Priority Lane: Option P2

Appendix B

Photometric Tests of LED Lanterns

This Appendix provides photometric test results of LED signal lanterns in relation to the luminous intensity standards in AS 2144 when viewed at various angles from the beam axis. The results assist in the assessment of conspicuity and visibility of overhead or side mounted signals. When positioning signal equipment other factors also need to be considered such as the driver’s field of vision.

PHOTOMETRIC TEST RESULTS RED ATS LED													
Degrees up from beam axis	Minimum luminous intensity												
	Degrees left from beam axis						Degrees right from beam axis						
	25	20	15	10	7.5	5	0	5	7.5	10	15	20	25
15						167.4	169.6	165.2					
10						228.3	234.8	191.3					
7.5						289.1	302.2	221.7					
5						345.7	354.4	247.8					
3						373.9	367.4	258.7					

Degrees down from beam axis	Minimum luminous intensity												
	Degrees left from beam axis						Degrees right from beam axis						
	25	20	15	10	7.5	5	0	5	7.5	10	15	20	25
0				125		250	250	250		125			
3					125		250		125				
5		19					125					19	
7.5			31								31		
10							31						
15	19												19
20							19						
25						67.4	64.0	56.5					
30						30.0	28.8	26.1					
35						15.1	14.6	13.9					
40						9.2	9.3	8.7					

Note: AS 2144 – Black Measured Intensity – Red

Part 3: Motorway Planning and Design

PHOTOMETRIC TEST RESULTS YELLOW ATS LED													
Degrees up from beam axis	Minimum luminous intensity												
	Degrees left from beam axis						Degrees right from beam axis						
	25	20	15	10	7.5	5	0	5	7.5	10	15	20	25
15						333.3	347.7	343.1					
10						442.7	517.9	443.4					
7.5						541.5	633.0	513.5					
5						630.8	684.2	543.9					
3						670.5	711.3	549.9					
Degrees down from beam axis	Minimum luminous intensity												
	Degrees left from beam axis						Degrees right from beam axis						
	25	20	15	10	7.5	5	0	5	7.5	10	15	20	25
0			260		520	250	520		260				
3					260		520	260					
5		39			260				39				
7.5			65								65		
10							65						
15	39												39
20							39						
25						132.5	133.4	120.3					
30						64.9	64.6	59.2					
35						33.4	33.2	30.9					
40						19.7	19.9	18.7					

Note: AS 2144 – Black

Measured Intensity – Yellow

Part 3: Motorway Planning and Design

PHOTOMETRIC TEST RESULTS GREEN ATS LED													
Degrees up from beam axis	Minimum luminous intensity												
	Degrees left from beam axis						Degrees right from beam axis						
	25	20	15	10	7.5	5	0	5	7.5	10	15	20	25
15						282.6	284.8	254.4					
10						441.3	373.5	384.8					
7.5						500.0	506.5	458.7					
5						528.3	567.4	500.0					
3						552.2	615.2	515.2					
Degrees down from beam axis	Minimum luminous intensity												
	Degrees left from beam axis						Degrees right from beam axis						
	25	20	15	10	7.5	5	0	5	7.5	10	15	20	25
0			138		275	275	275	275	138				
3					138		275		138				
5		21					138					21	
7.5			34								34		
10							34						
15	21												21
20							21						
25							41.3	43.5	39.1				
30							26.8	27.1	27.2				
35							23.9	22.6	23.9				
40							19.6	19.7	19.6				

Note: AS 2144 – Black Measured Intensity – Green

Appendix C

Glossary of Traffic Terms and Relationships

Algorithm	Programmed logic sequence within the ramp metering system which transforms traffic data and operator input into traffic control commands.
Asynchronous flow (stable flow)	Traffic speeds at or near the free-flow speed with almost unlimited freedom to manoeuvre within the traffic stream. Low flow rates. No breakdown risk.
Bottleneck	A fixed location where the capacity is lower than the upstream capacity.
Capacity	The maximum sustainable flow rate at which vehicles reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period in a specified direction under prevailing roadway, geometric, traffic, environmental and control conditions.
Capacity Drop	<p>A reduction in traffic flow from the maximum flow caused by flow breakdown (as generally used in traffic literature). The “capacity drop” represents a major economic loss due to less vehicles being serviced by the infrastructure.</p> <p>The authors have purposefully moved away from general use of the “Capacity Drop” terminology as it is not considered to be consistent with the definition or general use of the term “capacity” or the methods by which capacity is determined – in either the traditional or contemporary sense.</p> <p>The term “Flow Loss” is generally used in this Design Guide to better reflect the measurable loss that is being communicated.</p>
Catastrophe Theory	In mathematics, catastrophe theory is a branch of bifurcation theory in the study of dynamical systems; it is also a particular special case of more general singularity theory in geometry. Bifurcation theory studies and classifies phenomena characterized by sudden shifts in behaviour arising from small changes in circumstances, analysing how the qualitative nature of equation solutions depends on the parameters that appear in the equation. This may lead to sudden and dramatic changes.
Cycle	A complete sequence of signal phases.
Density	Number of vehicles per unit length of lane or roadway at a given instant in time (vehicles per km)
	$\text{Density} = \frac{\text{Flow}}{\text{Speed}}$
Downstream	In the direction of the movement of traffic
Flow Breakdown	The condition where free-flowing traffic experiences significant and sudden reduction in speed (for a certain minimum time period - typically a 15 minute period is used), usually combined with a sustained loss of traffic flow (throughput). This may result in queuing upstream of the bottleneck.
Flow Loss	A reduction in traffic flow due to flow breakdown (generally termed “Capacity Drop” in some literature). Flow Loss represents a major economic loss due to less vehicles being serviced by the infrastructure. Flow Loss is generally associated with a corresponding Speed Drop.

Flow rate (Flow)	The number of vehicles passing a given point on a lane, carriageway or road per unit of time, typically expressed in vehicles per second or an equivalent number of vehicles per hour.
Gap	The space length (m/veh) between the passage of consecutive vehicles moving in the same traffic stream, measured between the rear of the lead vehicle and the front of the following vehicle.
Headway	The time between the passage of the front ends of two successive vehicles in the same traffic stream.
	$\text{Headway (s)} = \frac{3600}{\text{Flow (veh/h)}}$
Hysteresis	The lag in a variable system property with respect to the effect producing it. For example, in traffic flow, the sudden reduction in speed and flow that occurs as traffic becomes congested does not generally recover at the same rate. There is a lag until density reduces such that speeds and traffic flow can recover.
Level of Service (LOS)	Qualitative measure that characterises operational conditions within a traffic stream. The six levels of service are from A to F with LOS A representing the best operating conditions and LOS F the worst (refer Appendix A).
Mainline	The main through carriageway as distinct from ramps and collector-distributor roads. This is the carriageway carrying the main flow of traffic and generally passes straight through at an interchange.
Managed motorway	Motorways managed with coordinated ramp metering signals. May also include management with other integrated ITS tools (i.e. ramp metering, VSL/LUMS and traveller information working together) as outlined in Volume 2, Part 1.
Maximum Sustainable Flow Rate	Volume that corresponds to a certain (limited) flow breakdown probability over a certain time (e.g. 1% over 15 minutes or 10% over a 3-hour peak period).
Meta-stable flow (transitioning free flow/metastable)	Free-flow traffic state, typically with high flow / density. When small perturbations (disturbances) occur, the state of free-flow traffic is still stable. However, when larger disturbances occur in the neighbourhood of a bottleneck, the free-flow traffic becomes unstable and flow breakdown can emerge (i.e. increasing breakdown risk, potentially transition to synchronised flow or congestion). Declining speeds due to increasing flows with decreasing freedom to manoeuvre within the traffic stream. Moderate to high flow rates. Increasing breakdown risk.
Motorway	A divided roadway with no access for traffic between interchanges and with grade separation at all road junctions. It includes urban freeways and tollways.
Nucleation	A micro factor occurring in the presence of other precursor conditions is typically the actual trigger(s) of a change in the traffic state. An example is a lane change into a smaller than desirable gap which coincides with the localised density being close to critical density. In traffic a nucleation event may not always result in flow breakdown or congestion as the state change may not linger.

Occupancy	<p>The proportion of time that a length of roadway or traffic lane is covered by vehicles, usually expressed as a percentage.</p> <ol style="list-style-type: none"> 1. Occupancy is used as a surrogate for density in control systems as it is easier to measure. However, there is no direct (proportional) relation between occupancy and density. 2. Occupancy values are related to the detector configuration. Therefore operational values may vary according to the detector size and spacing. Occupancy measures may be normalised to represent a fixed detector footprint to enable comparable results from different technologies and layouts.
Oscillations	<p>Spatiotemporal changes in Flow Rate / Speed / Density / Occupancy due to a forward moving wave or similar that may grow in amplitude and create the conditions under which flow breakdown is more likely.</p>
Peak Hour Factor (PHF)	<p>The ratio of maximum hourly volume to the maximum 15 minute flow rate expanded to an hourly volume. PHF is a measure of traffic demand fluctuation within the peak hour.</p>
Perturbation (Disturbance)	<p>Spatially and temporally confined interruption of homogeneous traffic flow characteristics which can be caused by individual vehicle manoeuvres or vehicle groups (e.g. inappropriate lane changing or abrupt braking) and which can cause larger scale inhomogeneities (e.g. oscillations or nuclei).</p>
Productivity	<p>Mathematical product of Flow Rate and speed.</p>
Shock Wave	<p>Shock waves are defined as boundary conditions in the time-space domain that demark a discontinuity in the flow density conditions (May 1990).</p> <p>A shock wave is a moving location within the traffic stream where an abrupt change of traffic conditions occurs, generally with free flow upstream and congested flow immediately downstream of the moving shock wave.</p>
Spacing	<p>The distance between the front ends of two successive vehicles in the same traffic lane.</p> $\text{Spacing (m)} = \frac{\text{Headway (s)} \times \text{Speed (km/h)} \times 1000}{3600}$
Speed	<p>The distance travelled by a vehicle per unit of time, typically expressed in metres per second or kilometres per hour.</p>
Speed Drop	<p>A reduction in traffic speed due to flow breakdown. This contributes to significant losses in economic efficiency and productivity by the infrastructure.</p>
Surface road	<p>A road that has a motorway interchange where vehicles may enter and leave the motorway. A surface road may be an arterial road or a local road.</p>
Synchronised flow (congested)	<p>Traffic speeds low with very limited freedom to manoeuvre within the traffic stream. Moderate to low flow rates (volatile). Traffic has broken down.</p>
System Performance Drop	<p>Loss in safety, throughput and productivity over a defined length or share (percentage) of a motorway corridor or network.</p>
Throughput (Flow / Flow rate / Volume)	<p>The number of vehicles per unit time passing a given point on a lane, carriageway or road, typically expressed in vehicles per hour (veh/h) or vehicles per day (veh/d).</p>

Upstream	In the direction opposite to the movement of traffic
Volume (Flow / Flow rate / Throughput)	The number of vehicles per unit time passing a given point on a lane, carriageway or road, typically expressed in vehicles per hour (veh/h) or vehicles per day (veh/d).

Notes: Where available, the definitions above are generally consistent with Austroads Guides to Traffic Management and the TRB Highway Capacity Manual.

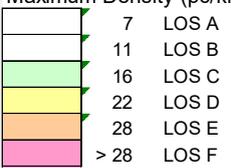
Level of Service

The HCM (2016) uses Level of Service (LOS) to define the various operating characteristics for uninterrupted traffic flow. A brief summary of the LOS traffic conditions and corresponding density ranges are provided in the table below.

LOS	Description	Freeway Facility Density pc/mi/ln (pc/km/ln)	
		Urban	Rural
A	Free-flow operations where vehicles are almost completely unimpeded in their ability to manoeuvre within the traffic stream.	≤ 11 (7)	≤ 6 (4)
B	Reasonably free flow conditions where the ability to manoeuvre within the traffic stream is only slightly restricted.	11-18 (7-11)	6-14 (4-9)
C	Traffic speeds at or near the free-flow speed with noticeably restricted freedom to manoeuvre within the traffic stream.	18-26 (11-16)	14-22 (9-14)
D	Declining speeds due to increasing flows with seriously limited freedom to manoeuvre within the traffic stream.	26-35 (16-22)	22-29 (14-18)
E	Operations at or near capacity which are highly volatile because there are virtually no usable gaps within the traffic stream; unstable with no ability to dissipate even the most minor disruption.	35-45 (22-28)	29-39 (18-24)
F	Unstable flow with queues forming behind bottlenecks. Breakdowns occur for a number of reasons.	> 45 (28)	> 39 (24)

Table C.1: Level of Service (LOS) description and density ranges

Traffic Flow Relationships:

Flow - Headway - Speed - Density - Spacing - Productivity													
Flow (pc/h/lane) ->	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
Av. Headway (s) ->	3.60	3.27	3.00	2.77	2.57	2.40	2.25	2.12	2.00	1.89	1.80	1.71	1.64
Speed (km/h)	Average Density (pc/km/lane)												
30	33.3	36.7	40.0	43.3	46.7	50.0	53.3	56.7	60.0	63.3	66.7	70.0	73.3
40	25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5	45.0	47.5	50.0	52.5	55.0
50	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0
60	16.7	18.3	20.0	21.7	23.3	25.0	26.7	28.3	30.0	31.7	33.3	35.0	36.7
70	14.3	15.7	17.1	18.6	20.0	21.4	22.9	24.3	25.7	27.1	28.6	30.0	31.4
80	12.5	13.8	15.0	16.3	17.5	18.8	20.0	21.3	22.5	23.8	25.0	26.3	27.5
90	11.1	12.2	13.3	14.4	15.6	16.7	17.8	18.9	20.0	21.1	22.2	23.3	24.4
100	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0
Legend: Maximum Density (pc/km/lane) and Level of Service (LOS) 													
Note: Flows greater than 2200 veh/h may not be sustainable for an hour but could occur for short flow periods													
Flow (pc/h/lane) ->	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
Av. Headway (s) ->	3.60	3.27	3.00	2.77	2.57	2.40	2.25	2.12	2.00	1.89	1.80	1.71	1.64
Speed (km/h)	Average Spacing (m)												
30	30.0	27.3	25.0	23.1	21.4	20.0	18.8	17.6	16.7	15.8	15.0	14.3	13.6
40	40.0	36.4	33.3	30.8	28.6	26.7	25.0	23.5	22.2	21.1	20.0	19.0	18.2
50	50.0	45.5	41.7	38.5	35.7	33.3	31.3	29.4	27.8	26.3	25.0	23.8	22.7
60	60.0	54.5	50.0	46.2	42.9	40.0	37.5	35.3	33.3	31.6	30.0	28.6	27.3
70	70.0	63.6	58.3	53.8	50.0	46.7	43.8	41.2	38.9	36.8	35.0	33.3	31.8
80	80.0	72.7	66.7	61.5	57.1	53.3	50.0	47.1	44.4	42.1	40.0	38.1	36.4
90	90.0	81.8	75.0	69.2	64.3	60.0	56.3	52.9	50.0	47.4	45.0	42.9	40.9
100	100.0	90.9	83.3	76.9	71.4	66.7	62.5	58.8	55.6	52.6	50.0	47.6	45.5
Flow (pc/h/lane) ->	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
Av. Headway (s) ->	3.60	3.27	3.00	2.77	2.57	2.40	2.25	2.12	2.00	1.89	1.80	1.71	1.64
Speed (km/h)	Productivity (veh-km/h², /1000)												
30	30	33	36	39	42	45	48	51	54	57	60	63	66
35	35	39	42	46	49	53	56	60	63	67	70	74	77
40	40	44	48	52	56	60	64	68	72	76	80	84	88
45	45	50	54	59	63	68	72	77	81	86	90	95	99
50	50	55	60	65	70	75	80	85	90	95	100	105	110
55	55	61	66	72	77	83	88	94	99	105	110	116	121
60	60	66	72	78	84	90	96	102	108	114	120	126	132
65	65	72	78	85	91	98	104	111	117	124	130	137	143
70	70	77	84	91	98	105	112	119	126	133	140	147	154
75	75	83	90	98	105	113	120	128	135	143	150	158	165
80	80	88	96	104	112	120	128	136	144	152	160	168	176
85	85	94	102	111	119	128	136	145	153	162	170	179	187
90	90	99	108	117	126	135	144	153	162	171	180	189	198
95	95	105	114	124	133	143	152	162	171	181	190	200	209
100	100	110	120	130	140	150	160	170	180	190	200	210	220

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