Published by:
VicRoads
Network and Asset Planning
60 Denmark Street
Kew VIC 3101

VicRoads Bookshop:

Electronic copies of the Handbook and Standard Drawings are available on the VicRoads Website:

Authors:
Maurice Burley (Consultant) and John Gaffney (VicRoads) from the Monash-CityLink-Westgate Upgrade (M1) Project, Ramp Metering Team.

Technical Review:
Development of this Handbook has included:

<table>
<thead>
<tr>
<th>VicRoads Advice and Consultation</th>
<th>External Review</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network and Asset Planning</td>
<td>Prof. Markos Papageorgiou and Ioannis Papamichail, Technical University of Crete.</td>
</tr>
<tr>
<td>Technical Consulting</td>
<td>A number of traffic consultants and interstate road authorities.</td>
</tr>
<tr>
<td>Technical and Information Services – \ Tim Strickland (data analysis applications).</td>
<td></td>
</tr>
<tr>
<td>Road Safety and Network Access.</td>
<td></td>
</tr>
<tr>
<td>Regional Services.</td>
<td></td>
</tr>
<tr>
<td>Major Projects.</td>
<td></td>
</tr>
</tbody>
</table>

ISBN  978-0-7311-9146-8
© VicRoads March 2010
Reprinted with amendments July 2013

Keywords:
FOREWORD

Managed Freeways

Freeway Ramp Signals Handbook

This Handbook has been issued by VicRoads to provide the rationale and criteria for managing freeway traffic flow with freeway ramp signals to control freeway access. The Handbook supersedes the ‘Guidelines for Managing Freeway Operation with Ramp Metering’ dated November 2005.

The Handbook is to be used as the primary reference for determining the need for freeway ramp metering as well as in the design and operation of ramp signals. The Handbook is the result of a major review of previous ramp metering guidelines and is based on contemporary traffic flow theory and state-of-the-art technologies as well as innovation associated with the design and operation of the Monash-CityLink-Westgate Upgrade (M1) Project.

A standardised system is essential to ensure that drivers acquire the information necessary to enable them to comply with road rules and to use the road system in a safe and efficient manner. In the interests of uniformity, other Victorian road authorities are encouraged to apply the requirements of this Handbook to freeways / tollways under their control.

This Handbook is one of a series of VicRoads guidelines relating to managed freeways including:
- Managed Freeway Guidelines;
- Managed Freeways: Freeway Ramp Signals Handbook; and
- Managed Freeways Handbook:
  - Lane Use Management
  - Variable Speed Limits
  - Traveller Information

Enquiries or comments relating to the Handbook may be directed to:

Director Network Policy and Standards
Policy and Programs
VicRoads
60 Denmark Street
Kew VIC 3101

Tel: 03-9854 2015  Fax: 03-9854 2918
Contents

1 Safe, Reliable and Efficient Freeway Operation 11
1.1 Managed Freeways – Introduction 12
1.2 Freeway Ramp Signals – An Overview 12
1.3 Context within an Integrated System 13
1.4 Background 13
1.5 This Handbook 14

2 Principles of Freeway Traffic Flow 15
2.1 Traditional Traffic Flow Relationships 16
  2.1.1 Freeway Theoretical Capacity 17
  2.1.2 Quality of Freeway Traffic Flow 18
  2.1.3 Freeway System Capacity 19
2.2 Contemporary Traffic Flow Theory 19
  2.3 Traffic Flow Breakdown 20
    2.3.1 Probability of Flow Breakdown 21
    2.3.2 Causes of Traffic Flow Breakdown 22
      2.3.2.1 Bottlenecks 22
      2.3.2.2 Other Causes of Flow Breakdown 23
      2.3.2. Effects of Flow Breakdown 24
        2.3.2.1 Creation and Effects of Shock Waves in Traffic 24
        2.3.2. Recovery from Flow Breakdown 26
2.4 Freeway Operational Capacity 27
  2.4.1 Recent Research 27
  2.4.2 Other Freeway Design Manuals 28
  2.4.3 Capacity at Freeway Entry Ramp Merges 29
  2.4.4 Merge Capacity for a Managed Freeway with Ramp Signals 30
  2.4.5 Operational Capacity Values for Freeway Design 30
2.5 Transport Sustainability 31
  2.5.1 Resilience in Transport Systems 31
  2.5.2 Building a Resilient Freeway 31

3 Principles of Freeway Ramp Metering 33
3.1 A Managed Freeway System 34
3.2 Freeway Ramp Signals in a Managed Freeway 34
  3.2.1 Context and Effectiveness 34
  3.2.2 Principal Aims of Freeway Ramp Metering 35
  3.2.3 Ramp Metering as a Management Tool 35
  3.2.4 Benefits of Ramp Metering 36
3.3 Interface at Arterial Road Interchanges 36
  3.3.1 General Principles 36
  3.3.2 Entry Ramps 37
  3.3.3 Exit Ramps 37
3.4 Ramp Metering Control 38
  3.4.1 Local Control 38
  3.4.2 Coordinated (Route-Based) Control 39
  3.4.3 Fixed Time Operation 41
  3.4.4 Dynamic Operation 41
3.5 Managing Ramp Demands 41
  3.5.1 Satisfying Ramp Demands 41
  3.5.2 Not Satisfying Ramp Demands 42
6.4.3.1. Freeflow and Partially Controlled Priority Lane (Drg. No. 541797) 83
6.4.3.2. Metered Priority Lane (Drg. No. 541798) 84
6.4. Three and Four Lanes at the Stop Line (Drg. Nos. 541795 & 541796) 87
6.4.5. Freeway to Freeway Ramp Metering (Drg. No. 453912) 87
6.4.6. Controller Location 91
6.4.7. Signal Pedestals 91
6.4.8. Signal Lanterns 91
6.4.10. Ramp Detectors 93
6.4.10.1. Stop Line Detectors 93
6.4.10.2. Middle of Ramp Queue Detectors 93
6.4.10.3. Ramp Entrance Detectors 93
6.4.10.4. Queue Overflow Detectors 94
6.4.11. Poles for Wireless Detector Receivers 94
6.4.12. Ramp Control Signs and Real Time Information Signs 94
6.4.12.1. RC1 Warning and Regulatory Sign 95
6.4.12.2. RC2 Warning Sign 95
6.4.12.3. RC3 Sign - Real Time Information Sign 96
6.4.13. Other Signs 97
6.4.14. Pavement Markings 97
6.4.15. CCTV Cameras 98
6.4.16. Power Supply and Communications 98
6.4.17. Lighting 98

7 Operation of Ramp Signals 99
7.1. Legal Basis for Ramp Signals 100
7.2. Control Algorithms used by VicRoads 100
7.3.1. Dynamic Activation and Deactivation 101
7.3.2. Time of Day Activation 101
7.3.3. During Incidents and Events 101
7.3.4. Manual Operation 101
7.4. Switching on/off Signs and Signals 101
7.4.1. Start-up Sequence 101
7.4.2. Close-down Sequence 103
7.5. Operating Sequence and Cycle Times 104
7.5.1. Signal Timings 104
7.5.2. Minimum Cycle Time 104
7.5.3. Maximum Cycle Time 104
7.6 HERO Ramp Metering Operation 106
7.6.1. Overview 106
7.6.2. HERO Operation 106
7.6.2.1. Activation / Deactivation 107
7.6.2.2. ALINEA Core Module 107
7.6.2.3. Critical Occupancy Estimation Module 107
7.6.2.4. Queue Estimation Module 107
7.6.2.5. Queue Control Module 107
7.6.2.6. Queue Override Module 107
7.6.2.7. HERO Coordinated Operation 107
7.6.2.8. Minimum Queue Control Module 108
7.6.2.9. Final Ramp Flow Specification Module 108
7.6.2.10. Implementation Module 108
7.6.3. Enhancements to Provide Advanced Bottleneck Control (ABC) 108
7.7. Ramp Signals Response to Emerging Congestion 108
  7.7.1. General Principles 108
  7.7.2. Ramp Signals Control 109

7.8. Ramp Signals Integration with other Managed Freeway Operations 110
  7.8.1. Ramp Signals Response to a Lane Closure 110
  7.8.2. Ramp Signals Response to Changing Speed Limits 110
  7.8.3. Ramp Signals Response to a Freeway Closure 110
  7.8.4. Emergency Vehicle Access when Ramp Signals are Operating 110

8 Arterial Road Access Management 111
  8.1. General Principles 112
  8.2. Managing Entry Ramp Queue Overflows 112
    8.2.1. Potential Ramp Problems 112
    8.2.2. Treatment Options 112
  8.3. Managing Exit Ramp Queuing 113
    8.3.1. Potential Mainline Problems 113
    8.3.2. Treatment Options 114
    8.3.3. Exit Ramps Design Storage 115

Appendices 117
  APPENDIX A: Freeway Ramp Signals - Information Bulletin 118
  APPENDIX B: Short History of Ramp Metering 122
  APPENDIX C: Photometric Test Results of LED Lanterns 135
  APPENDIX D: Congestion Management with Ramp Signals 138
  APPENDIX E: Glossary of Terms and Traffic Flow Relationships 139
  APPENDIX F: References 141
Notations and Abbreviations

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

A Glossary of Terms and Traffic Flow Relationships is provided in Appendix E.
Chapter 1
Safe, Reliable and Efficient Freeway Operation
1.1. Managed Freeways – Introduction
Melbourne’s freeway and tollway network\(^1\) carries 30% of the arterial road traffic although comprising only 7% of the arterial road network length. The efficient use of freeways and tollways is essential in providing a safe and reliable level of service that maximises the productivity of the asset and provides optimum operation in relation to throughput and travel time.

An actively managed freeway may incorporate a number of traffic management tools which provide a range of benefits. The most effective traffic management tool for managing freeway flow to achieve high levels of efficiency and reliability is access control with coordinated freeway ramp signals.

1.2. Freeway Ramp Signals – An Overview
Freeway ramp signals are traffic lights installed on an entry ramp to meter traffic into the freeway in a measured and regulated manner in order to manage the freeway traffic flow and prevent congestion. Flow breakdown and congestion reduce throughput, increase travel time and represent underutilisation and lost productivity of a high value facility.

An actively managed coordinated system of ramp signals based on contemporary traffic flow theory can provide stable and reliable travel by optimising throughput and travel speed on the freeway as well as preventing, or delaying, the onset of traffic flow breakdown and congestion.

VicRoads use of the HERO suite of algorithms provides coordinated dynamic management of Melbourne’s freeways. This provides proven results in achieving the objectives of managed freeways.

Figure 1.1: Freeway Ramp Signals

Local ramp metering controls the entry of traffic at a ramp based on local freeway bottleneck conditions as well as ramp data. This is isolated operation that is independent of what is happening at other entry ramps.

Coordinated freeway ramp signals use a dynamic algorithm that makes a combined decision based on data from the freeway and a number of entry ramps. This operation is able to regulate the entry of traffic from a number of ramps to address the overall freeway objectives and to balance flows between ramps.

General information relating to freeway ramp signals is provided in an information bulletin in Appendix A.

\(^1\) Includes the actual and estimated 2008 median midweek non-holiday 24 hour volume for the Inner and Outer Metropolitan Statistical Division as defined by Australian Bureau of Statistics.
The US Federal Highway Administration has issued a ramp metering information brochure (2006) which includes the following comment summarising the success of ramp metering:

_No other traffic management strategy has shown the consistently high level of benefits in such a wide range of deployments from all parts of the country._

Pete Briglia, Puget Sound Regional Council, Seattle, Washington and Chair of the TRB Freeway Operations Committee.

### 1.3. Context within an Integrated System

Managed freeways with coordinated freeway ramp signals operate within the VicRoads road network management framework as shown in Figure 1.2.

Further information relating to the integration of freeway ramp signals within a managed freeway environment is provided in Section 3.1. Information relating to the arterial road interface is in Chapter 8.

![Figure 1.2: VicRoads Road Network Management](image)

### 1.4. Background

In 2002 VicRoads commenced the installation of ramp metering at freeway interchanges to reduce traffic flow congestion on the freeway and to improve merging. The entry ramp metering at each site operated in an isolated manner with a fixed time cycle to manage the rate at which vehicles could join the freeway.

In 2008 the trial of dynamic coordinated ramp metering signals resulted in increased freeway performance and greater reduction of flow breakdown. This was based on the effective management of inflows over a length of freeway to match the capacity of the mainline at each merge as well as the critical bottlenecks.

A short history of ramp metering in Melbourne and internationally is in Appendix B.
### Chapter 1: SAFE, RELIABLE AND EFFICIENT FREEWAY OPERATION

#### 1.5. This Handbook

This Handbook provides the rationale, criteria and design principles for providing freeway ramp signals. The Handbook structure includes:

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction, background and context of managed freeways and freeway ramp signals.</td>
</tr>
<tr>
<td>2</td>
<td>Principles of freeway traffic flow including background relating to fundamental and contemporary traffic flow relationships and traffic flow breakdown leading to congestion.</td>
</tr>
<tr>
<td>3</td>
<td>Principles of ramp metering including the principal aims and benefits, managing the arterial road interface and the principles of operation to control access and prevent flow breakdown.</td>
</tr>
<tr>
<td>4</td>
<td>Criteria for providing freeway ramp signals on existing and new freeways or ramps.</td>
</tr>
<tr>
<td>5</td>
<td>Importance of reliable freeway traffic data and analysis.</td>
</tr>
<tr>
<td>6</td>
<td>Guidelines for capacity analysis and design, including typical layouts for freeway ramp signals.</td>
</tr>
<tr>
<td>7</td>
<td>Operation of ramp signals including an outline of the algorithms used by VicRoads and traffic management relating to emerging congestion and other tools in a managed freeway.</td>
</tr>
<tr>
<td>8</td>
<td>Managing the arterial road interface – entry ramps and exit ramps.</td>
</tr>
</tbody>
</table>

#### Appendices

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Freeway Ramp Signals - Information Bulletin.</td>
</tr>
<tr>
<td>B</td>
<td>Short history of ramp metering.</td>
</tr>
<tr>
<td>C</td>
<td>Photometric test results of LED lanterns.</td>
</tr>
<tr>
<td>D</td>
<td>Congestion management using ramp signals and traveller information signs.</td>
</tr>
<tr>
<td>E</td>
<td>Glossary of terms and traffic flow relationships.</td>
</tr>
<tr>
<td>F</td>
<td>References.</td>
</tr>
</tbody>
</table>
Chapter 2
Principles of Freeway Traffic Flow
This section provides a summary of traffic flow theory and principles that relate to managing freeway traffic flow. The summary is provided to briefly explain the principles and terminology used in this Handbook as well as provide background for understanding the operation and benefits of freeway ramp metering which are outlined in Chapter 3.

A glossary of terms and a summary of traffic flow relationships are outlined in Appendix E. Further information related to traffic flow theory is available in some reference documents listed in Appendix F.

### 2.1. Traditional Traffic Flow Relationships

The three basic parameters used to describe traffic flow states are flow rate (volume), speed and density. The theoretical relationships between the three basic parameters on freeways are often referred to as the ‘fundamental relationships’ of ‘uninterrupted’ traffic flow.

Freeway traffic flow is considered to be ‘uninterrupted flow’ based on relationships where the flow is governed by internal traffic interaction and where flow is not interrupted or affected by external factors such as traffic signals or intersections. The ‘fundamental diagrams’ that indicate the relationships are shown in Figure 2.1.

![Figure 2.1: Fundamental Diagrams: Speed-Density-Flow Relationships for Uninterrupted Flow](Source: Based on Austroads Guide to Traffic Management Part 2: Traffic Theory)

The Austroads Guide to Traffic Management Part 2: Traffic Theory (2008) provides the following description of traffic conditions represented by the diagrams:
At the points A in each part of the figure, density is close to zero, that is, there are very few vehicles on the road. Volume is also close to zero and there are no interactions between vehicles in the traffic stream to prevent drivers from travelling at their desired speeds, the average of which will be the mean free speed, $v_f$.

From A to the vicinity of B, traffic conditions can be described as ‘free flow’, in which each vehicle suffers very little restriction due to other traffic in the stream. Such restrictions start to become quite significant as the point B is passed. This could be considered the region of normal flow, in which drivers experience an increasing lack of freedom to manoeuvre (e.g. change lanes, change speed) but traffic nevertheless moves steadily at a reasonable speed, at least until conditions in the vicinity of C are reached.

As the point C is approached, traffic conditions become very unstable and substantial fluctuations in both speed and density can occur with very little change in volume. C is the point of maximum achievable volume and any further increases in density only decrease speed to such an extent that volume also decreases rapidly. Traffic is operating in the ‘forced flow’ region from C to D, the ultimate condition of which is reached at D, where volume is zero because the traffic is stationary at a maximum density (‘bumper-to-bumper’ condition) termed the jam density.

Thus, a driver would perceive excellent traffic conditions in the region of A, deteriorating gradually from A to B and towards C, and becoming poor to bad around C and from C to D.

The above relationships and previous work outlined in the US Transport Research Board Highway Capacity Manual 2010 (HCM) form the basis of traditional ‘two phase’ traffic flow theory. The maximum flow occurs when flow is stable just before flow breakdown occurs. Subsequent flow is then at a lower speed until flow recovers.

When collecting flow data, lane occupancy (proportion of time over which there is a vehicle present at a specified point) is measured by vehicle detectors and is proportional to density. Occupancy is used in traffic control systems as it is easier to measure compared with measuring density.

2.1.1. Freeway Theoretical Capacity

The Highway Capacity Manual (2010) defines capacity as:

The maximum sustainable hourly flow rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, environmental, traffic, and control conditions.

The HCM indicates the maximum theoretical capacity of a freeway segment under ideal conditions with free-flow speed in the order of 100 km/h, is 2,300 pc/h/ln. The actual capacity of a freeway includes adjustments for various factors such as:

- Traffic characteristics including composition of the traffic stream, e.g., trucks, as well as the familiarity of drivers with the freeway; and
- Roadway characteristics including vertical alignment, e.g., an upgrade or vertical curve in a tunnel, horizontal alignment, e.g., tight radius curve, number and width of lanes, lateral clearances and lane configurations, e.g., merge, weaving and diverge areas or lane drops. Locations with restricted capacity relative to upstream sections of the freeway are bottlenecks where flow needs to be managed to reduce the potential for flow breakdown.

The concept of passenger car equivalents (PCE) is related to traffic behaviour due to the vehicle mix (i.e. 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 freeway capacity analysis heavy vehicles are converted into an equivalent number of passenger cars to achieve a consistent measure of flow.
In measuring the capacity it is generally ‘the maximum sustained 15-min flow rate, expressed in passenger cars per hour per lane (pc/h/ln), that can be accommodated by a uniform freeway segment under prevailing traffic and roadway conditions in one direction of flow.’

The flow rate measured over a short period is generally not sustained over a longer period. The ratio of maximum hourly volume to the maximum 15 minute flow rate expanded to an hourly volume is the peak hour factor (PHF). The PHF is a measure of traffic demand fluctuation within the peak hour and is typically up to 0.95 in high flow conditions.

2.1.2. Quality of Freeway Traffic Flow

The HCM (2010) uses Level of Service (LOS) to define the varying operating characteristics for uninterrupted flow. The various LOS are defined to represent ranges in the three critical flow variables of speed, density, and flow rate. A summary of LOS descriptions are:

**LOS A** describes free-flow operations where vehicles are almost completely unimpeded in their ability to manoeuvre within the traffic stream.

**LOS B** represents reasonably free flow conditions where the ability to manoeuvre within the traffic stream is only slightly restricted and the general level of physical and psychological comfort provided to drivers is still high.

**LOS C** provides for flow with speeds at or near the free flow speed. Freedom to manoeuvre within the traffic stream is noticeably restricted, and lane changes require more care and vigilance on the part of the driver.

**LOS D** is the level at which speeds begin to decline slightly with increasing flows and density begins to increase more quickly. Freedom to manoeuvre within the traffic stream is more noticeably limited, and the driver experiences reduced comfort levels.

**LOS E** describes operation at capacity. Operations at this level are volatile, because there are virtually no usable gaps in the traffic stream. Vehicles are closely spaced leaving little room to manoeuvre within the traffic stream. At capacity, the traffic stream has no ability to dissipate even the most minor disruption, and any incident can be expected to produce a serious breakdown with extensive queuing.

**LOS F** describes a breakdown in vehicular flow. These conditions generally exist at locations where flow breakdown occurs and within queues forming behind breakdown points. Breakdowns occur where the number of arriving vehicles is greater than the number of vehicles that can move through the area, i.e., traffic demand exceeds the capacity. This may be:
- A point where a traffic incident occurs
- Points of recurring congestion, such as merge or weaving segments or lane drops.

The objectives of managing the freeway flow with freeway ramp signals are to avoid flow breakdown and resulting congestion and to optimise the flow rate (throughput) and travel speed. This focuses on managing traffic demand within the critical values of occupancy (density) at locations with restricted capacity as outlined in Section 3.6.1, i.e., where excessive flow, or short high variations within the traffic flow, can trigger flow breakdown and cause congestion.

Traditional traffic flow theory in the HCM provides background on several free flow states where there is spare freeway capacity (LOS A to D). However, the HCM generally describes a two phase model, i.e., flow before and after flow breakdown, and provides limited information for understanding the management of high flow freeways at critical values of LOS E, nor does it adequately describe the complex dynamics of traffic behaviour under congested conditions within LOS F.
2.1.3 Freeway System Capacity

The capacity of freeway segments can be affected by various geometric features such as grades, tight curves and narrow sections (lanes or clearances) as well as influence areas such as merge areas, diverge areas and weaving areas.

The HCM 2010 defines freeway facility capacity as:

- The capacity of the critical segment among those segments composing the defined facility. This capacity must, for analysis purposes, be compared with the demand flow rate on the critical segment.
- The ‘critical segment’ is defined as the segment that will break down first, given that all traffic, roadway and control conditions do not change, including the spatial distribution of demands on each component segment.

Figure 2.2 shows a typical freeway system with various bottlenecks at entry ramp merges. The critical bottleneck is the segment which governs the capacity of the freeway system, i.e., the ‘weakest link’ along the route. Therefore, the operating conditions at the critical segment has a significant effect on the performance of the route as a whole.

2.2. Contemporary Traffic Flow Theory

Contemporary traffic flow research has sought to provide an understanding about the mechanisms that lead to flow breakdown and recovery as well as traffic behaviour under congested conditions. This focus is necessary for:

- Analysing congested freeways and identifying solutions to improve throughput.
- Developing improved design methodologies for new projects or freeways being upgraded.
- Developing tools for managing freeway flow to prevent flow breakdown, including control logic for coordinated ramp signalling.
- Developing tools for managing flow to restore free flowing conditions after flow breakdown, e.g., after an incident or where flow breakdown could not be prevented.
- Developing improved theory for realistic traffic behaviour models and simulation tools.

Research by Kerner B S (2004) based on empirical (measured) data has found that traditional traffic flow models and related simulation tools cannot explain and cannot predict traffic flow breakdown and some other traffic phenomena. Kerner classifies freeway flow into the three traffic phases described below and as shown in Figure 2.3:

- **Free flow** where drivers can choose their own speed;
- **Congested traffic in synchronised flow** where the density becomes high, the speed reduces and the traffic state is metastable, i.e., stable but in delicate equilibrium where it is susceptible to fall into lower-energy states with only slight interaction. The emerging flow breakdown is generally fixed at a bottleneck where the downstream front of the congestion separates the synchronised flow from the downstream free flow traffic;
Congested traffic in a wide moving jam where there is a very high density of traffic and the jam propagates upstream through any other traffic states. Within the jam, vehicle density is very high and speed is very low with vehicles becoming stationary in some instances. Within the upstream jam front, vehicles slow down approaching the jam. At the downstream jam front, vehicles accelerate away from the congested area.

Figure 2.3: Examples of Congested Traffic Patterns

Helbing and Schonhof (2004) have investigated the characteristics and properties of congested traffic states from data in Germany and a number of other countries. The paper identifies five different kinds of spatio-temporal congestion patterns and their combinations.

The research and development by Papageorgiou et al (1991, 1997 and other more recent work) relating to freeway flow and access control logic has provided significant applications of theory for avoiding congestion, controlling traffic flow and operating freeway ramp metering.

An appreciation of contemporary traffic theory generally leads to a conclusion that congested freeways require management of a system rather than treatments in isolation. State-of-the-art control systems aim to identify conditions that can lead to congestion, filter out normal background variability in data, and respond rapidly when freeway conditions fall outside various limits. The development of coordinated control systems focus on the causes of congestion and the prevention of flow breakdown by managing traffic flow within control thresholds, rather than treating the symptoms or effects of congestion.

Note:
Research relating to contemporary traffic theory is relatively new, which can give rise to uncertainty in relation to findings and application of the theory to traffic design and operations. However, significant similarities have been identified relative to causes of flow breakdown and congestion patterns observed in Melbourne that are beyond the scope of understanding problems using traditional traffic theory. Observation of factors that contribute to congestion include site specific features, traffic flow demands, speeds, driver behaviour and detector dependability (availability at suitable locations, accuracy and reliability) to facilitate analysis.

Nevertheless, contemporary traffic flow theory has increased the level of knowledge that can be applied to freeway design and traffic flow management. Future applications will improve the accuracy and reliability of traffic models when evaluating improvement proposals. Further research and innovation is necessary.

2.3. Traffic Flow Breakdown
Traffic flow breakdown is the condition where free-flowing traffic experiences significant and sudden reduction in speed, with a sustained loss of throughput. Traffic flow breakdown can occur at any location on a freeway regardless of the design standard (refer Section 2.3.2).
Just prior to flow breakdown the flow on the freeway exceeds capacity. As flow breakdown occurs the speed may drop by 20-40 km/h within minutes. This change in the state of flow may be caused by an incident, traffic disturbance or by increasing volume to the point where the traffic flow becomes unstable. In the context of Level of Service (LOS), the flow breakdown generally occurs within LOS E where unstable flow leads to problems in sustaining the free flowing conditions. The changes to speed and flow rate are accompanied by increases in freeway lane occupancies (density values within LOS F).

Figure 2.4 is an example of traffic flow breakdown. Data is shown for each lane on a 3 lane carriageway. The flow breakdown at this location was initiated by an uncontrolled flow at an entry ramp merge.

Figure 2.4: Chart Depicting Traffic Flow Breakdown

2.3.1. Probability of Flow Breakdown

Lorenz and Elefteriadou (2001), Brilon, Geistefeldt and Regler (2005) and Brilon and Geistefeldt (2009) discuss the reliability of freeway traffic flow and the stochastic concept of capacity. These papers indicate that the capacity of a freeway facility is not so much deterministic, but rather a random variable, and that breakdown probability can be related to traffic flow as shown in Figure 2.5. Examples of flow values and the likely flow breakdown probability at those flows are shown plotted on the graph.
2.3.2. Causes of Traffic Flow Breakdown

Traffic flow breakdown occurs within the section of a freeway where the flow first exceeds capacity. The flow breakdown occurs due to a range of factors when high mainline flows are not sustainable.

2.3.2.1. Bottlenecks

A bottleneck is a fixed location where the capacity is lower than the upstream capacity. Bottlenecks that affect traffic flow capacity and cause the potential for flow breakdown typically include:

- Merging traffic from an entry ramp
- Merging traffic at a lane drop, e.g., narrowing from 4 to 3 lanes
- High lane changing manoeuvres over a short distance – typically due to weaving prior to a high flow exit or prior to an increase in the number of lanes
- Traffic queues at an exit ramp extending back to block the left lane of the freeway or causing traffic to slow down prior to exiting
- Mainline locations where geometric features cause vehicles to slow down e.g. a steep upgrade, a tight radius curve, width restriction (real or perceived) or sight distance constraint.

‘Critical’ bottlenecks are the locations along a section of freeway where flow breakdown usually occurs first, i.e., the location that first reaches capacity. These are typically at a lane drop or at an entry ramp merge with a combination of high mainline flow and a high entry flow. As flow breakdown at a bottleneck relates to an operational deficiency, recurring congestion is generally predictable and can be managed with appropriate control of flow. In some instances a solution may exist to correct a deficiency.

A ‘potential’ or ‘latent’ bottleneck becomes an ‘active’ bottleneck when flow breakdown occurs as a result of the flow exceeding capacity, i.e., the congestion is not the result of a shockwave that arrives from a downstream location as outlined in Section 2.3.2.1.
2.3.2.2. Other Causes of Flow Breakdown

Traffic flow breakdown can also occur at any location on a freeway due to:

- Speed differential between vehicles, e.g., due to trucks;
- An accident, object or other incident on the carriageway;
- Road works including maintenance works;
- Driver behaviour that slows down the traffic flow such as:
  - ‘rubber necking’ to look at an incident
  - police presence or enforcement activity
  - random actions such as sudden braking following a driver’s inattention;
- A lower speed limit; and
- Triggering by short periods of very high density flow that are not sustainable. An example of spikes in traffic flow data is in Figure 2.6.

Source: VicRoads 20 October 2008

*Figure 2.6: Example of High Volume and Density ‘Spikes’ in the Traffic Flow*
2.3.2. Effects of Flow Breakdown

Freeway traffic flow breakdown usually creates significant reductions in throughput and vehicle speeds and may result in substantial increases in travel time. During the period of flow breakdown, lane occupancy (density) rises as a result of reduced headway on the freeway. The reduction in throughput, which may average about 10-15 per cent, represents under-utilisation of a high value facility and lost productivity. An example is shown in Figure 2.7.

Figure 2.7: Typical Flow Breakdown Impacts on Traffic Throughput and Speed

After traffic flow breakdown occurs at a bottleneck, the congestion will result in slow speed travel at that location and loss of throughput, i.e., capacity flow is only reached for a relatively short time. The symptoms may be localised and remain at or near the bottleneck, or more usually, the congestion creates a moving queue with a shockwave that travels upstream from the initial location of flow breakdown, to affect the performance of an extended length of the freeway.

2.3.2.1. Creation and Effects of Shock Waves in Traffic

A shock wave is a moving location within the freeway traffic stream where an abrupt change of traffic conditions occurs, generally with free flow upstream and congested flow downstream of the shock wave location. With increasing demand the congestion promulgates upstream in the form of a shock wave, i.e., slow and faster moving traffic. Figure 2.8 shows an example of freeway flow breakdown as well as the resulting shock wave propagation upstream. Typical characteristics within the shock wave area are:

- The lane occupancy will be high
- Flow rates will typically be 10% to 20% lower than the maximum flow at the downstream bottleneck prior to breakdown; and
- The speed will be low and variable as the shock wave moves upstream, i.e., stop-and-go waves are formed within the congested area.
As the congestion moves in shock waves from the point of initial flow breakdown, i.e., a critical bottleneck, the congestion at a particular upstream location may be the result of a bottleneck that is remote from the area under investigation. When investigating the cause of congestion at a particular point or when trying to identify the critical bottleneck along a length of freeway, it needs to be determined whether the data represents congestion from flow breakdown at that point or whether the congestion results from a downstream bottleneck, i.e., there is a need to differentiate between cause and symptom.

A data analysis related to the identification of a critical bottleneck location is shown in Figure 2.9. The example indicates that the flow at the bottleneck reached capacity while flows within the shock wave area were significantly lower than the capacity.

- Flow – Occupancy graph at a critical bottleneck.
- Note flow breakdown occurs at capacity (approx. 2200 veh/h).
- Flow – Occupancy graph within the shock wave area upstream of a critical bottleneck.
- Note maximum flow rate (approx. 1800 veh/h) is lower than capacity.
**Note:**

Shockwaves are defined as boundary conditions in the time-space domain that demark a discontinuity in the flow density conditions (May 1990). May also describes the following types of shock waves:

- Frontal stationary
- Backward forming
- Forward recovery
- Rear stationary
- Backward recovery
- Forward forming

Research by Schonhof and Helbing (2004) also describe a ‘boomerang effect’ in simulation results where a congested traffic pattern may also travel downstream.

Lighthill and Whitham (1955) indicates the propagation speed of a shock wave at the boundary of the congestion’s space-time surface can be calculated from the difference between the congested area flow and the upstream arrival flow divided by the difference between the congested and upstream densities. If the arriving flow is higher than the congestion flow then the tail of the shock wave is moving upstream. If the arriving flow is lower than the congestion flow, e.g., at the end of the peak period, then the congestion is dissolving and the tail of the shockwave is moving downstream.

Australian research (Austroads 2009) indicates that the backward forming shock wave on the Monash Freeway in Melbourne travels upstream against the traffic flow at an average of 26 km/h with overseas research indicating speeds from 17 km/h to 20 km/h (USA), 22 km/h to 24 km/h (Canada) and rural freeway shockwave speeds of 6 km/h to 20 km/h (UK and Germany respectively).

### 2.3.3. Recovery from Flow Breakdown

Whilst the mechanism for breakdown follows the general pattern described in the fundamental diagram, the recovery from flow breakdown follows a different phenomenon generally known as the hysteresis of traffic flow. As observed by Brilon et al., (2005), after flow breakdown all recoveries to fluent traffic passed through synchronised flow (the transient state) and involved much lower traffic volumes than the preceding breakdown as shown in the examples in Figure 2.10.

---

**Figure 2.10: Two Typical Patterns of Traffic Dynamics during Breakdown and Recovery**

Source: Brilon et al., (2005) - Freeway section A5-7, 5-minute flow rates
Traffic flow breakdown and recovery observed on Melbourne’s freeways exhibit similar characteristics. An example that shows the path of flow breakdown and recovery is provided in the speed/flow graphs in Figure 2.11. This theory is applied in the HERO suite of algorithms used for ramp metering by VicRoads (refer Section 7.6.2).

Figure 2.11: Example of flow Breakdown and Recovery

2.4 Freeway Operational Capacity

2.4.1 Recent Research

Roess (Jan 2009) carried out research relating to the HCM speed-flow curves as ‘one of the “fill-the-gap” research tasks of Task 6 of NCHRP 3-92. The investigation that was based on a data base consisting of 48 basic freeway sites over nine states in the US has provided significant information relating to actual freeway capacity flows relative to the HCM theoretical values.

The chart relating to free-flow speed (FFS) at 60 mi/h (96.6 km/h), i.e., similar to 100 km/h urban freeways in Australia, is shown in Figure 2.12. The red line indicates the HCM capacity and the data points from the investigation are plotted in blue. The data indicates that the maximum flow attained for a short period prior to flow breakdown was less than 2,100 pc/h/ln and that the flow at breakdown was approximately 1,900 pc/h/ln. These operational capacity values are significantly less than the theoretical capacity value of 2,300 pc/h/ln generally used in design applications.
Figure 2.12: Speed-flow Data and HCM Capacity for FFS of 60 mi/h (~100 km/h)

Other research by Brilon and Geistefeldt (2009) provide a modified definition of capacity as:

*Capacity is the maximum flow rate that achieves acceptable traffic performance of the facility and beyond which – in case of greater demand – proper operation fails.*

The transition from ‘proper’ operation to non-acceptable flow conditions is flow breakdown which is characterised by a relatively sudden speed reduction. Brilon and Geistefeldt (2009) also indicate that a freeway operates at the highest expected efficiency if the demand volume reaches 90% of the conventional design capacity. Applying this factor to the HCM capacity of 2,300 pc/h/ln results in a ‘highest efficiency’ flow of 2,070 pc/h/ln.

### 2.4.2 Other Freeway Design Manuals

The German Manual for the Design of Road Traffic Systems (2005) provides measures that define the quality of traffic flow (Levels A to F). These levels are based on degree of saturation rather than density. The mainline capacities for freeways with speed limits of 100 and 80 km/h on grades up to 2% are shown in Table 2.1 below. The values are at least 10% lower than the HCM capacity values.

<table>
<thead>
<tr>
<th>Number of Lanes</th>
<th>Capacity (veh/h)</th>
<th>Heavy Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>10%</td>
</tr>
<tr>
<td>3</td>
<td>5,800</td>
<td>5,500</td>
</tr>
<tr>
<td>Flow / lane</td>
<td>1,933</td>
<td>1,833</td>
</tr>
<tr>
<td>2</td>
<td>4,100</td>
<td>3,900</td>
</tr>
<tr>
<td>Flow / lane</td>
<td>2,050</td>
<td>1,950</td>
</tr>
</tbody>
</table>


Table 2.1: German Freeway Mainline Capacities for 2 and 3 Lane Carriageways
The UK Design Manual for Roads and Bridges, Volume 6 Section 2 Part 1 TD 22/6 provides guidelines for the selection of entry ramp layout for freeways of varying mainline and merging flows. The guideline includes a chart for the selection of an appropriate entry ramp layout. In regard to traffic flows (Chapter 3) it indicates:

For the purpose of designing grade separated junctions and interchanges, the maximum flow per lane for motorways must be taken as 1,800 vehicles per hour (vph). These flows do not represent the maximum hourly throughputs but flows greater than these will usually be associated with decreasing levels of service and safety.

The ITE Freeway and Interchange Geometric Design Handbook (2006) provides guidelines for entry ramp capacity assessment. The merge capacity varies according to the upstream mainline flow and the entry ramp merging flow. For example, the mainline capacity is in the order of 2,000 veh/h/ln with no entry ramp flow. The capacity reduces to approximately 1,600 veh/h/ln with an entry ramp flow of 800 veh/h, i.e., approximately 20% capacity drop due to the merging traffic.

2.4.3. Capacity at Freeway Entry Ramp Merges

Contemporary traffic research has also provided insights in relation to the capacity of entry ramp merges. Research on Japanese freeways by Shawky and Nakamura (2007) indicates that an increasing ratio of entry ramp flow to outflow rates leads to a higher breakdown probability, as shown in Figure 2.13. For example, for a flow of 2,000 veh/h/ln, flow breakdown probability increases from approx. 25% with a 10% ratio of entry ramp flow to outflow, to a probability of 85% at a flow ratio of 30%.

Figure 2.13: Observed and Estimated Breakdown Probability at the Shibekoen Ramp
Cassidy and Rudjanakanoknad (2002) when studying traffic at a freeway merge and the roles of ramp metering found that as entry ramp flows increase the downstream capacity (throughput) reduces as shown in Figure 2.14.

![Figure 2.14: Freeway Entry Ramp Capacity with Increasing Ramp Flows](image)

**Figure 2.14: Freeway Entry Ramp Capacity with Increasing Ramp Flows**

### 2.4.4. Merge Capacity for a Managed Freeway with Ramp Signals

A managed freeway with state-of-the-art coordinated ramp signalling technology has the ability to optimise density and capacity by managing the carriageway occupancy and minimising flow breakdown.

Chapter 3 shows examples of the effectiveness of a freeway which has ‘managed operation’ with coordinated ramp signals. The unmanaged flow results in flow breakdown, reduced throughput, reduced speed, congestion and lost productivity for the freeway. The managed flow results in optimum throughput and speed as the system controls and minimises the potential for flow breakdown as well as automating flow recovery when the flow nears the point of breakdown (refer Figure 3.2). While higher values can be achieved in practice, a value in the order of 2,000 veh/h/ln (2,100 pc/h/ln) is generally more sustainable over a range of conditions.

Optimum speeds and high capacity flow can only be achieved and maintained over a prolonged period by controlling density with coordinated freeway ramp signals.

### 2.4.5. Operational Capacity Values for Freeway Design

When designing freeway projects or upgrading of existing freeways, operational capacity values should be used rather than theoretical values to gain an appropriate understanding of how the project will perform after construction and to ensure that adequate infrastructure is provided for the anticipated demands.

Based on recent research and operational investigations, appropriate maximum capacity values for freeway design are:

- **Unmanaged freeways**: 1,800 pc/h/ln (typically 1,700 veh/h/ln) which accepts a low risk of flow breakdown
- **Managed freeways**: 2,100 pc/h/ln (typically 2,000 veh/h/ln) with well designed infrastructure and a state-of-the-art coordinated ramp metering system, e.g., VicRoads HERO algorithm
The above values may need to be adjusted for site specific conditions which will impact freeway capacity, including road characteristics and vehicle mix.

2.5. Transport Sustainability

2.5.1. Resilience in Transport Systems

Sustainable transport systems need to optimise efficiency relating to sustainable living. Transport management also needs to provide best outcomes for the environment.

Resilience is an important component of sustainable systems. Resilience is the ability to perform under stress and absorb a ‘shock’ as well as the ability to recover in the event of failure. The degree of resilience also relates to the rate at which the system returns to a steady state following the cause of a disturbance.

2.5.2. Building a Resilient Freeway

When considering the resilience of a freeway, performing under stress includes managing high demands as well as adjusting to factors that could lead to collapse. A ‘shock’ would include flow breakdown, heavy congestion or an incident.

In building a resilient freeway the system processes include:

- Designing the infrastructure and traffic management systems to minimise the causes of flow breakdown
- Identifying optimum performance and avoiding over supply that would cause congestion, i.e., identifying ‘safe’ thresholds and working to them with a technically effective coordinated ramp metering system
- Providing coping mechanisms if flow breakdown or an incident occurs as well as appropriate interventions to facilitate flow recovery from congestion, e.g., efficient identification and management of incidents as well as managing flow recovery by restricting entering traffic with ramp signals and providing traveller advice to divert traffic
- Having an automated control system that can monitor, manage and initiate required actions as well as provide information to assist motorists in their travel choices.
Chapter 3
Principles of Freeway Ramp Metering
3.1. A Managed Freeway System

An integrated freeway management system may interface a number of real time on-road traffic management tools such as:

- A coordinated freeway ramp signals system to manage freeway access and assist in preventing flow breakdown
- Congestion management. This may be used to supplement the overall freeway access management strategy. The ramp metering operation would restrict entry to assist in preventing a worsening of congestion and to assist in flow recovery
- Traveller information including travel time. Information for drivers is provided on the freeway mainline and on the arterial roads at entry ramp intersections. This may include information about planned future events, e.g., roadworks, current incidents ahead or travel time information to enable drivers to make informed decisions relating to route choice. Travel time information on the arterial road includes travel on the mainline as well as ramp delays
- Incident management. Effective detection and management of incidents assists in minimising flow disruption. This requires integration with lane use management, variable speed limit, congestion management and traveller information systems in the support of incident management personnel
- Lane use management. This system assists in dealing with incidents or events on the freeway. The system is integrated with the traveller information system
- Variable speed limits. This system assists in controlling vehicle speeds during incidents, events or adverse weather.

3.2. Freeway Ramp Signals in a Managed Freeway

3.2.1. Context and Effectiveness

Within the context of a ‘managed freeway’ which may incorporate a range of traffic management tools, controlling the entering traffic with a coordinated freeway ramp signals system that incorporates a technically effective algorithm is the most effective tool in managing flow to prevent flow breakdown and optimise capacity and travel time on the mainline.

Figure 3.1 shows an example of a high entry merge where mainline flow is managed to prevent flow breakdown and optimise freeway throughput and speed.

The occupancy at this freeway bottleneck downstream of a high flow entry ramp merge is managed to:

- Prevent flow breakdown
- Optimise speed
- Optimise flow (throughput).

Location: Monash Freeway inbound between Ferntree Gully Road and Blackburn Road (Midblock Data Station 7972), 28/07/2008. Morning peak period.

*Figure 3.1: Example of Flow, Speed and Occupancy relationships (Fundamental Diagrams) at a Bottleneck Managed with Ramp Metering*
3.2.2. Principal Aims of Freeway Ramp Metering

The principal aims of metering traffic on freeway entry ramps are:

1. To optimise freeway throughput, travel speed and travel time reliability

This is achieved by minimising the possibility of flow breakdown on the freeway and the consequential rapid development of congestion. Travel time reliability is provided by reducing variability from day to day. The principal actions are:

- Headway management of entering traffic, i.e., dispersing platoons (bunching) of vehicles entering from the ramp to achieve an evenly distributed flow of traffic into the merge area
- Managing the flow rate of entering vehicles in a ramp merge area when the freeway is near capacity, i.e., by managing the entry flows within limits beyond which the mainline traffic flow would typically transition to an unstable condition
- Ensuring the overall mainline freeway volume is within the bottleneck capacity at critical bottlenecks along the freeway, generally by coordinating traffic from a number of ramps.

2. To improve safety

This is achieved by:

- Reducing the potential for incidents due to braking and stop-start flow during unstable conditions or when flow breaks down
- Assisting merging
- Minimising lane changing, particularly in the vicinity of an entry ramp, e.g., lane changing caused by drivers trying to avoid delays in the left lane when there is no metering
- Minimising turbulence in areas of high weaving.

3.2.3. Ramp Metering as a Management Tool

Metering of freeway entry ramps provides an effective traffic management tool for managing the mainline traffic in a number of ways including:

- Controlling and coordinating all entry ramps along a route to manage the mainline freeway at a number of critical bottleneck locations. This will ensure that the best overall freeway service is delivered under a wide range of conditions and contribute to reducing the variability of travel time from day to day, thus enhancing improved reliability
- Managing the freeway flow (occupancy) in a way that would prevent or delay freeway flow breakdown at an isolated bottleneck
- Controlling entry ramp traffic to facilitate faster restoration of free flowing conditions after congestion caused by a crash or other unplanned incident
- Managing the headway of entering ramp traffic onto the mainline. This can assist in merging and improve safety even when the ramp traffic does not need to be restricted to optimise mainline capacity
- Discouraging short trips on the freeway during periods of high demand or congestion.

Figure 3.2 shows charts of freeway flows for unmanaged and managed situations. In the managed freeway example, controlling the vehicle access has prevented flow breakdown and maintained free flowing conditions.
### 3.2.4. Benefits of Ramp Metering

There are a number of benefits that result from the principal aims of ramp metering. These include:

- Reduced delay for users of high-volume freeways
- A more reliable service to freeway users
- Reduced number of mainline traffic incidents and the consequential impacts of such events
- Increased freeway throughput at critical times and locations
- Enhanced overall road network travel times. The gain in better operation of the freeway more than offsets the additional time taken for traffic to enter the freeway and the localised congestion occurring at arterial roads near interchanges
- Equitable use of the road network including redistributed traffic in keeping with infrastructure capacity and discouraging the use of the freeway system for short trips during periods of high flow
- Improved road safety due to safer management of merging traffic and more stable freeway travel speeds i.e., reduction in stop-start traffic conditions
- Reduced fuel consumption and emissions as a result of efficient travel conditions.

### 3.3. Interface at Arterial Road Interchanges

#### 3.3.1. General Principles

The arterial road interchanges and the road network connecting with the freeway need to be integrated and then managed for an effective freeway / arterial road interface.

The VicRoads Freeway Operational Objectives (2004) indicate that:

*The economic imperative is 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.*
Generally, if the freeway is able to carry more traffic in the peak periods, it follows that the operation of arterial roads may also improve, compared to a situation where freeways remain unmanaged.

The implications at arterial road interchanges relate to the management, capacity and operation of entry ramps and exit ramps. Interfacing of the freeway management system and the arterial road signal system (SCATS) is also necessary at some locations.

It is also desirable to provide information for motorists on the arterial road relating to estimated freeway travel time or incidents before they enter the freeway. This is achieved with strategically located signs to assist motorists with their route choice decisions (refer Section 6.4.12).

3.3.2. Entry Ramps

The management of traffic entering the freeway will produce an increase in the freeway throughput at critical locations, and generally, the freeway as a whole (refer Sections 2.3.2 and 3.2.4). As demand for freeway travel increases it will be necessary to limit the amount of entering traffic so that the mainline capacity at any point is not exceeded, i.e., to ensure that high levels of freeway service are sustained.

Metering will create local delays at entry ramps, i.e., the ramps act as a ‘retarding basin’ to ensure the freeway traffic flow is optimised, rather than excess demand ‘flooding’ onto the freeway and causing vehicles to ‘store’ on the freeway. While ramp signals may be perceived as a cause of delay, for most freeway trips the improved freeway flow will result in lower overall delay.

At some locations excess demand will need to be constrained to achieve the overall benefits and the overflow of queues onto the arterial road may need to be addressed (refer Section 6.3.5 and 8.2), particularly when there is inadequate entry ramp storage. An interface with the arterial road SCATS system is also able to transfer information that enables integrated control strategies to be implemented.

A concern about ‘overflow’ effects on a connecting arterial road needs to be seen alongside the overall traffic management objective. Experience has also shown that trip diversion from metered ramps to other routes also occurs, e.g., the initial installation of ramp signals on the Monash Freeway / Warrigal Road outbound entry ramp resulted in significant redistribution of ramp demand. As well as changes to travel routes, motorists have also changed their times of travel to achieve acceptable journey travel times. This has resulted in a spread of the peak travel periods.

There will be situations where a redistribution of demand should be sought as a managed outcome. In these situations, the availability of alternate routes and the adequacy of the arterial network to accommodate route diversions need to be considered. The diversion of traffic is most effective where there is a well connected arterial road network and/or a significant proportion of entering traffic is undertaking short trips.

Generally, when compared with not having ramp metering, congestion on arterial roads with freeway ramp signals is not worse and in some cases can be improved. In situations where managing freeway flows at a bottleneck leads to creating undesirable conditions on a connecting arterial road, consideration should be given to increasing capacity at the critical freeway bottleneck, increasing storage capacity of the ramp or providing additional storage on the approaches as outlined in Section 8.2.

3.3.3. Exit Ramps

Traffic flow on the freeway mainline is affected when traffic queues on an exit ramp extend back to block the left lane of the freeway or cause traffic to slow down prior to exiting. In these situations the accessible freeway capacity is reduced through reduced availability of the left lane for through traffic. Vehicles also change lanes to avoid the left lane which increases turbulence and potential for flow breakdown on the mainline. A significant safety concern is also created for left turning vehicles as well as through vehicles.

The management of entering traffic with ramp signals will generally produce an increase in the freeway throughput which will also result in increased exit flows. This problem may also become significant when existing freeways are upgraded without increases in capacity at interchanges.

Further information relating to the management of exit ramp queuing is provided in Section 8.3.
3.4. Ramp Metering Control

Ramp signals for a managed freeway would generally be part of a route treatment that operates as a system under dynamic, coordinated control.

When ramp signals are coordinated in a system, the ability to manage the mainline occupancy and flow by matching total entry ramp inflows to the capacity of a critical bottleneck along the freeway is significantly improved. System control also has the advantage of distributing entry ramp queues and waiting times across a number of ramps to provide equity between access points.

Generally all entry ramps would be signalled, including ramps leading to added lanes on the freeway and freeway to freeway (system interchange) ramps. Management of all entering traffic maximises the ability to control and manage downstream traffic conditions.

Ramp meters may operate under the following levels of control:

- **Local Control** – when a single ramp is operating independently and does not interact with adjacent entry ramps. Isolated ramp signals on a freeway without connection to other upstream ramp signals would operate under local control, and

- **Coordinated Control** – when ramp signals along a freeway operate within an interlinked and coordinated ramp metering system. Ramp signals within a coordinated system may operate under local control when they first switch on or when downstream entry ramps can manage inflows without needing to enlist the assistance of upstream ramps to manage queues

The broad principles associated with operating ramp meters under local and coordinated control are described below. The detail relating to the real time operation of ramp signals and an overview of the algorithms used by VicRoads is in Chapter 7.

3.4.1. Local Control

Local ramp meter control may be appropriate where it can be demonstrated that entering traffic causes flow breakdown in the mainline flow at an isolated bottleneck that generally has no impact on, or from, other interchanges along the route.

The function of a local ramp meter is to manage the entering rate of traffic to overcome the impact of large uncontrolled platoons of traffic coming from the ramp’s upstream intersection signals. An isolated meter may also be used to control the total entering volume to maintain stable conditions when the freeway is nearing capacity.

In its simplest form, calculation of the metering flow to minimise the likelihood of downstream flow breakdown is shown in Figure 3.3 and is based on:

- Bottleneck capacity flow ($q_{cap}$)
- Upstream flow ($q_{US}$)
- Entry ramp arrival (demand) flow ($q_{ra}$), and
- Maximum metered ramp flow ($q_n$).
Local control for isolated ramp metering installations may be effective in providing reductions in merging problems and improvement of freeway traffic flow where there is a high merging flow, but:

- It has limited functionality and ability to balance operation along a route when compared with coordinated control, e.g.,
  - If the bottleneck capacity is less than the upstream flow there is no ability to control demand on the mainline
  - Subject to the algorithm operation and applied queue management strategy, this may result in earlier initiation of ramp queue override actions and premature flow breakdown at the merge
  - It provides reduced equity relative to upstream ramps, i.e., the ramp at the active bottleneck takes ‘all the pain’ while the upstream ramps, while contributing to bottleneck activation, are either not controlled or do not share delays equitably
- Is unlikely to be able to maintain optimum freeway throughput if there is congestion related to other bottlenecks along the route, and
- Is not generally recommended for heavily trafficked freeways where a number of entry demands need to be managed or where flow breakdown may occur at a number of locations.

The bottleneck flow capacity is used in ramp signal design to determine the maximum metered ramp flow rate, \( q_r \). This is then compared with the arrival (demand) flow, \( q_{ra} \) to determine whether the ramp demand can be satisfied (refer Section 6.3). The principle is also used in some control algorithms.

The algorithms in best practice systems use occupancy values related to the downstream bottleneck (refer Section 3.6).

### 3.4.2. Coordinated (Route-Based) Control

Best practice dynamic control allows for ramp signals to operate in an isolated manner or to engage, when needed, upstream ramps in a master/slave relationship.

When ramp meters are coordinated in a system it improves the ability to manage the mainline freeway flow by matching traffic inflows from a group of ramps to the capacity of a critical bottleneck along the route. It also has the capability of balancing the queues and wait times between ramps.
With coordinated control the freeway ramps are grouped into a manageable number of ramps that can operate together as a control system when traffic conditions require coordination. Typically, a coordinated control group would include a minimum of 6 to 10 ramps to provide control over a section of freeway within an overall freeway length. Control groups of this number provide a balance between long and short trips where, typically, only 50% of traffic entering at a particular ramp will travel more than 6 interchanges.

Within a coordinated group, bottlenecks could occur at many locations including each entry ramp merge and other locations of restricted capacity. The bottleneck where flow breakdown generally occurs first is the critical bottleneck. Other locations also need to be managed within the coordinated system but would be less dominant bottlenecks. The management and control of traffic flow along a length of freeway usually requires metering at all points where traffic enters the freeway. This may include:

- Entry ramps with merging traffic
- Entry ramps leading to an added lane
- Freeway to freeway entry ramps or metering of upstream ramps on the intersecting freeway, as appropriate (refer Section 4.4), and
- The start of the freeway in some instances.

The general principle of managing metered entry ramp flows within a coordinated system to match the capacity of a downstream critical bottleneck on the freeway, is shown in Figure 3.4 and the following paragraphs. Managing the freeway flow also takes into account the traffic leaving the freeway at exit ramps.

The ramp metering signals immediately upstream of the critical bottleneck generally becomes the 'master' and controls a coordinated group of ramps. Other upstream ramps are activated to become 'slaves' in the coordinated group to provide assistance in managing the overall entry flows.

![Figure 3.4: Metering Traffic with Coordinated Control](image)

**Note:** Less dominant bottlenecks would also exist at each entry ramp merge

In this example:

\[ \sum q_{rn} \text{ (max)} = q_{cap} - q_{us} + \sum q_{ex} \]

where \( q_{cap} \) is the bottleneck capacity.

The control system would control the total flow allowed to enter the freeway, \( \sum q_{rn} \text{ (max)} \), from the individual ramps to manage \( q_{r1}, q_{r2}, q_{r3}, \) and \( q_{r4} \) according to local control needs and an appropriate balancing of ramp queues and/or delays. Local control is also used to avoid flow breakdown at each localised entry ramp merge, i.e., each of the individual metered entry ramp flows would need to be managed so that the freeway capacity at each local ramp merge is not exceeded (refer Section 3.4.1).

The ramp metering signals immediately upstream of the critical bottleneck generally becomes the ‘master’ and controls a coordinated group of ramps. Other upstream ramps are activated to become ‘slaves’ in the coordinated group to provide assistance in managing the overall entry flows.

---

2 Internal VicRoads reports relating to travel on Monash Freeway and Western Ring Road.

3 Although not discussed in this handbook consideration may need to be given to the phase times of traffic signals at the start of a freeway to match the required capacity of downstream sections.
Coordinated ramp metering has the following benefits:
- Reduces mainline demand at a downstream bottleneck when local control cannot manage flow
- Provides equity by balancing of queues and delays between a number of ramps, i.e., shares the “pain”
- Reduces the likelihood of queue overflow on short ramps by transferring delay to ramps with more storage.

3.4.3. Fixed Time Operation

Fixed time ramp metering operation generally switches on according to time of day settings and then uses a fixed time signal cycle. In some situations a different cycle time is chosen based on ramp demand. Fixed time operation is able to drip-feed vehicles into the mainline that arrive on the ramp in platoons, but the operation does not adapt to changing freeway flow conditions. This form of operation can provide some benefit to mainline flow but has limited effectiveness in preventing flow breakdown and optimising freeway throughput.

3.4.4. Dynamic Operation

A dynamic ramp metering system adapts to changing traffic flows on the freeway and ramp. The system can manage traffic at the local level and in a coordinated system along a freeway corridor. A dynamic system generally includes the following capabilities:
- Switch-on occurs automatically when the freeway flow at a local merge or bottleneck is approaching unstable conditions. The dynamic system will fall back to fixed time operation if there are data problems from the system’s vehicle detectors or communications system,
- Automated response to freeway conditions by continually adjusting ramp inflows, i.e., cycle times, along the route to optimise freeway flow and travel speeds as well as balancing queues and managing traffic delay on the ramps. A range of parameters in the control system algorithm can be adjusted in real time to refine the operation, and
- Enhanced capability to prevent flow breakdown occurring at bottlenecks due to uncontrolled demand. It also provides more effective identification of, and response to, flow breakdown caused by an unplanned incident and can then manage inflows to the freeway to facilitate faster recovery as outlined in Sections 3.7 and 7.7.

Note:

Historically, ramp metering practice was often based on vehicles entering gaps in the left lane of the freeway. The important determinant is generally the total flow across all lanes and the related density of traffic. The contemporary approach considers traffic flow in all lanes across the whole carriageway. With a technically effective control algorithm this generally results in optimum flow in all lanes as well as optimum entry ramp flows.

3.5. Managing Ramp Demands

While all ramp metering operates to control the rate of traffic entry into the freeway, there are situations when the control may satisfy demand and situations when the ramp demand cannot be satisfied.

3.5.1. Satisfying Ramp Demands

Ramp demands are satisfied when the entry ramp flows can be metered into the freeway flow within acceptable limits of delay. This form of control ‘drip feeds’ entry ramp flows into the mainline in a way that, on average, generally clears entering traffic from the signalised ramp intersection before the next platoon of traffic arrives. Residual queuing, with acceptable delays, may occur on the ramp but without extending back into the ramp intersection.
Satisfying ramp demand is the most desirable form of operation and would usually be achieved when the freeway flow warrants initial activation of the metering signals. As the freeway flow or ramp flow increases into the peak period the level of operation may progress to more restrictive forms of metering.

When designing a new ramp metering installation, satisfying ramp demand on average throughout the whole of the design flow period (maximum hourly flows) is the desirable form of operation. In practice, the permitted entry flow at a particular ramp will be subject to the freeway flow condition at the time, as well as operating outcomes relating to the impact that queuing and queue balancing may have when the ramp is part of a coordinated system.

3.5.2. Not Satisfying Ramp Demands

Ramp demands cannot be satisfied when the arrival flow on the ramp within a period is greater than the maximum metering rate, i.e., on average throughout the analysis period, generally the peak period, the entry ramp demand flow cannot be metered into the freeway flow within acceptable limits of queuing or delay. In these circumstances it is likely that some traffic diversion to other routes will occur.

During periods of high freeway flow combined with high entry ramp demand, limiting the entry flow may be the only form of operation that sustains free-flow conditions on the freeway. This metering operation will result in residual queuing on the ramp with high delays and may also involve queues extending beyond the length of the ramp back onto the arterial road.

Where long queues during ramp metering operation are anticipated and cannot be avoided during design, consideration should be given to measures that provide for the queue overflow on the arterial road (refer Section 8.2). In practice, with coordinated ramp metering strategies in place, ramp demands over a group of ramps can generally be satisfied for a longer period due to the balancing of queues.

3.6. Control Strategies and Algorithms

3.6.1. Effective Algorithms

The choice of an appropriate control strategy and technically effective freeway flow control algorithm for coordinated ramp metering is important if the maximum efficiency of a freeway is to be realised. This needs to go hand in hand with sound analysis and an understanding of freeway flow characteristics and geometry as well as appropriately designed entry ramps to provide adequate capacity and storage. These matters are outlined in Chapters 6 and 7.

The Euramp Handbook of Ramp Metering (2007) illustrates in Figure 3.5 the implications of a ramp metering rate that is either too high or too low. In the typical fundamental diagram for flow versus occupancy the maximum flow $q_{\text{cap}}$ (capacity), occurs at a critical occupancy value, $o_{\text{cr}}$. At an isolated ramp when merging flow breakdown occurs due to entering traffic, the mainline flow drops to the area of $q_{\text{con}}$ (congestion).

Therefore if the ramp flow through metering signals is too permissive, merging congestion will still occur. If ramp metering is too restrictive, the mainline throughput could drop to values similar to $q_{\text{con}}$, which would negate any potential benefits as well as disadvantage entry ramp traffic, i.e., create longer ramp queues.

To achieve the full potential benefits of ramp metering, a technically effective ramp metering algorithm that establishes and maintains critical occupancy, i.e., maximum capacity flow conditions around the $q_{\text{cap}}$ value, is crucial.
Section 7.2 provides a summary of the operation of the HERO suite of ramp metering control algorithms used by VicRoads, including a summary of the features that lead to the choice of the algorithm for freeways in Victoria.

3.6.2. Why Occupancy is used to Manage Freeway Flow

The Euramp Handbook of Ramp Metering (2005) has highlighted the uncertainty of mainline ‘capacity’ and summarised the conclusions from a number of papers (Elefteriadou et al., 1995; Lorenz and Elefteriadou, 2001; Cassidy and Radjanakanoknad, 2005) that have demonstrated that traffic breakdown in merge areas may occur at different flow capacity values $q_{cap}$ on different days, even under similar environmental conditions, e.g., weather, lighting. These capacity differences become even more pronounced in adverse weather conditions (Keen et al., 1986).

In contrast, the critical occupancy $o_{cr}$ at which capacity flow occurs, was found to be fairly stable (Cassidy and Radjanakanoknad, 2005), even under adverse weather conditions (Keen et al., 1986; Papageorgiou et al., 2007). Therefore, the occupancy measurement is the appropriate parameter for optimising throughput rather than speed or flow rate.

3.7. Managing Heavy Congestion and Incidents

On a managed freeway with coordinated ramp signals flow breakdown is generally prevented, or at least its onset is delayed. When freeway congestion does occur, the management of ramp signals requires an automated and integrated operational strategy that will minimise the worsening of congestion and also assist in flow recovery.

Situations that could lead to heavy freeway congestion include:

- Insufficient control of entering flows:
  - Some entry ramps are not metered
  - A freeway-to-freeway ramp is not metered and there is insufficient control on the intersecting freeway upstream of the interchange
  - The entry to the managed freeway is not controlled, e.g., the freeway is the continuation of a rural freeway or an arterial road.
Access control strategies or policy lead to excessive demand:
- Ramps with free flow priority access lanes
- Queue management strategy to prevent ramp queues extending onto the arterial road lead to the implementation of high entry flows.

An incident on the freeway.

Figure 3.6 shows an example to demonstrate incident delay with cumulative vehicle arrivals and departures plotted against time. The shaded area between the arrivals and departures represents the vehicle delay due to an incident. Before the incident, the vehicle arrival rate equals the rate of the departures. After the incident traffic is delayed and the departure rate decreases.

The early identification and effective management of an incident as well as actions to reduce freeway demand can assist in minimising the impact on traffic flow. Figure 3.7 indicates how an effective incident management system reduces the overall impact of an incident as well as the time for the freeway flow to return to normal. This is due to:
- Faster incident detection and response that leads to earlier incident removal
- Diverting traffic away from the incident.

Figure 3.6: Incident Clearance without an Incident Management System

Source: Based on Austroads AP-R298/07 - Improving Traffic Incident Management: Evaluation Framework
Figure 3.7: Incident Clearance with an Incident Management System

An integrated approach is required to manage incidents and heavy congestion. This focuses on the following complementary actions:

1. **Management of entry flows to assist in flow recovery**

   Freeway ramp signals can be used to limit entry ramp flows upstream of the incident by implementing a high cycle time to minimise the entry flow rate. This reduces the freeway flow at the incident site and also assists in diverting traffic, particularly if traveller information relating to travel time and incidents is provided. An automated response within preset thresholds detects the onset of congestion due to oversupply of traffic or due to capacity limitations at the incident site.

2. **Closing entry ramps and/or the freeway.**

   In some situations managing the incident may also include closing ramps or the freeway upstream of an incident.

3. **Traffic diversion by providing traveller information**

   Some motorists will use an alternative route if travel advice is available. This can be provided by:
   - Real time driver information signs on the arterial road prior to the freeway entrance (refer Section 6.4.12)
   - Mainline VMS to encourage motorists to leave the freeway before reaching the congested section
   - Traffic condition reports from radio stations, particularly during peak periods.
3.8. When Ramp Metering has Limited Effectiveness

In some situations ramp signals can have limited effectiveness in preventing congestion due to conditions which limit capacity or traffic flow. These include:

1. Planned or Unplanned Events
   a) During road works if the capacity of the mainline is significantly restricted
   b) During incidents where sudden congestion occurs.

In these situations congestion management using coordinated ramp signals and traveller information advice can provide benefits for the duration of the event and can assist in flow recovery after the incident is cleared (refer Section 3.7).

2. Inadequate Traffic Management

When all entries to a freeway are not controlled, situations can arise where the uncontrolled flows dominate the freeway flow and limit the ability of ramp signals to prevent flow breakdown. In this situation, excessive restriction on entry flows would result in inequitable access to the freeway and excessive ramp delays.

3. Inadequate Infrastructure
   a) Where a freeway terminates at an arterial road intersection with limited capacity. If traffic cannot be accommodated at the end of the freeway, queues and congestion develop on the freeway mainline as shown in Figure 3.8. Upstream ramp metering cannot increase the freeway throughput as the intersection at the end of the freeway controls and limits the capacity. Although upstream metering would be able to reduce the extent of queuing, this could result in excessive entry ramp delays, unnecessary restriction of trips to upstream exits and underutilisation of the upstream sections of freeway.

![Figure 3.8: Freeway Congestion at a Terminating Freeway](image-url)
In this situation the provision of upstream ramp signals would still make a contribution to improving the overall freeway flow by providing other benefits such as:

- Headway management at upstream ramps to improve local merging
- Preventing flow breakdown on upstream sections of the freeway at ramp merges and other critical bottlenecks
- Balancing entry ramp queues and delays in a coordinated system.

Where queues from the end of the freeway extend beyond an upstream exit as shown in Figure 3.9, coordinated freeway ramp signals could assist in managing upstream entry flows to keep the exit clear.

**Figure 3.9: Freeway Congestion at a Terminating Freeway affecting an Upstream Exit**

b) Where an exit ramp or exit ramp intersection has inadequate capacity and queues extend back onto the freeway and block a freeway lane as shown in Figure 3.10. The management of exit ramp overflow queues is discussed in Section 8.3.

**Figure 3.10: Freeway Congestion from an Exit Ramp**

**Note:** Theoretically, ramp metering by destination could be used to alleviate the problems identified above. This would require lane designation on the entry ramps, separate meters and metering rates as well as enforcement. It has not been trialled at this stage.
Chapter 4
Criteria for Provision of Freeway Ramp Signals
4.1. Existing Freeways

4.1.1. Background Analysis
The analysis of freeway flow data will generally involve assessment of flow, speed and occupancy information along the freeway. This assessment is to identify bottlenecks at merges and other locations as well as consideration of the frequency and duration of flow breakdown from day to day or the potential for flow breakdown.

4.1.2. Isolated Locations
These will be locations where isolated ramp metering control may be provided because the breakdown of the mainline freeway flow is localised and clearly associated with platoons of traffic entering at a particular ramp. Generally, the localised flow breakdown will be unrelated to downstream congestion or high upstream flows.

4.1.3. Route Treatment
A route-based treatment will be required:
- Where the congestion and flow breakdown is occurring at a number of bottlenecks over a length of freeway, or
- Where flow breakdown occurring at a particular location cannot be addressed by an isolated ramp meter, i.e., the freeway flow causing the flow breakdown results from a combination of a number of upstream entry ramps, or
- Where the peak period traffic volume for the freeway mainline between interchanges is 1700 pc/h/ln or more, without flow breakdown.

Generally, in a route-based treatment, effective control of the freeway flow at a particular bottleneck can only be achieved by metering upstream entry ramps for a distance of at least six ramps. This also improves access equity via the balancing of ramp queues.

4.1.4. Provision at New Ramps on Existing Freeways
Where new ramps are being added to an existing freeway, ramp metering signals are to be provided in the following circumstances:
- Where other upstream or downstream ramps along the freeway are currently metered, or
- Where a need for metering along the route has been identified and the route is proposed for metering, or
- Where the peak period traffic volume for the freeway mainline between interchanges is 1700 pc/h/ln or more, with or without flow breakdown.

4.2. New Freeways
The consideration of ramp metering on new freeways or on connections or extensions to existing freeways is to be based on detailed investigation and analysis of anticipated peak traffic demand on the freeway within 10 years of opening.

Where the new freeway is extending or connecting to an existing freeway, it is necessary to recognise the potential impact of additional traffic on adjacent downstream, or upstream, sections of the existing freeway. The investigation must account for the expected additional traffic and possible redistribution of traffic. The impact may extend for a number of interchanges.

In undertaking this assessment the analysis should identify all freeway sections which meet the following conditions:
- The peak period traffic volumes are 1700 pc/h/ln or more for the mainline flow along any section of the new freeway,
- The new freeway results in the downstream peak volumes between interchanges on adjacent sections of freeway to increase above a value of 1700 pc/h/ln.
A route-based treatment would generally be necessary to provide effective control of the freeway flow at a particular bottleneck or over a length of freeway and to provide balancing of ramp queues for access equity. This would usually require metering of at least six entry ramps.

The business case or scope approval report for the project shall provide a summary of the findings of the above analysis, with a recommendation on whether ramp meters are required as part of the new freeway or freeway extension/connection project.

**Note:**

The criteria of 1700 pc/h/ln for provision of freeway ramp signals is based on a number of factors including:

- The probability of flow breakdown occurring. Research by Brilon et al (2005) indicates that at flows in this range there is approximately 5% to 10% probability of flow breakdown occurring (refer Figure 4.1). At 2000 veh/h/ln the probability is in the order of 50 to 60%.
- The objective of preventing flow breakdown, even at low levels of probability, given the economic impact that this can have on traffic efficiency and safety.
- The breakdown at entry ramp merges is a probabilistic rather than a deterministic event. Research by Elefteriadou et al (1995) indicates that reaching capacity flow is not a prerequisite for flow breakdown and that the clusters of vehicles from the ramp, rather than ramp flow, affect the ramp merge. Further comment relating to entry ramp merges is in Section 2.4.3.
- At mainline flows of this value, generally the entry ramp flows are also becoming significant.
- To provide a margin for future demand increase, and
- Consideration of traffic flows and the stability of flow on Melbourne’s freeways.

The use of pc/h/ln is due to the potential flow effects of heavy vehicles in the traffic stream.

---

**Figure 4.1: Probability of Flow Breakdown on a 3 lane Freeway**

---

Source: Brilon et al (2005)
4.3. Operational Standard for New Ramp Signals

All new ramp signals, including isolated ramp signals that are to be under local control, are to be designed and installed to operate dynamically within the VicRoads coordinated freeway ramp signals system utilising the HERO suite of algorithms. When compared to fixed time operation, the dynamic operation of ramp signals that adapt to changing traffic flows on the freeway has been shown to improve freeway flow and minimise flow breakdown (refer Appendix B).

4.4. Freeway to Freeway Ramps

The performance of a managed freeway is determined by its ability to minimise or avoid 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 freeway’s capacity. Therefore, the general principle is to control and regulate all traffic entering a managed freeway.

Freeway-to-freeway (system interchange) ramps provide connections between high speed facilities where drivers may not expect to stop, nor expect to encounter a queue of stopped vehicles. Generally, these ramps are high traffic flow environments where it is desirable to provide an uninterrupted freeway journey. Freeway to freeway ramps may also be difficult locations for provision of the widening and storage facilities required to manage metered traffic due to structures or fill. However, as flows entering a managed freeway from another freeway would contribute to the potential for flow breakdown on the managed freeway, ramp signals need to be considered. Where ramp metering is provided it would only operate when needed and uninterrupted free-flow operation would be available at other times. If flow breakdown does occur on the managed freeway this would impact not only the managed freeway but also the traffic from the entering freeway.

Metering the upstream entry ramps from arterial roads, rather than the freeway-to-freeway ramps, may be a workable strategy for managing the freeway-to-freeway merge and downstream section of freeway. But, where the intersecting freeway does not have entry ramp signals or where the upstream ramp metering is unable to provide the necessary management of entering flows and additional control is required to manage downstream flow on the mainline, freeway-to-freeway metering would generally be required. A further advantage of metering freeway-to-freeway ramps is that it would assist in the ability to manage traffic during incidents and improve the recovery from flow breakdown after an incident.

Where the intersecting freeway joins with the managed freeway as shown in Figure 4.2, the traffic from ramps immediately upstream of the interchange makes a significant contribution to the flow entering the managed freeway. The metering of several upstream ramps can then be used to control the traffic at the interchange merge as well as the downstream section of freeway.
Upstream ramps make a significant contribution to entering flows at interchange

Manage merge using upstream ramp metering

Figure 4.2: Traffic Flows at Freeways that Join

For interchanges where the major traffic flow crosses the managed freeway, as shown in Figure 4.3, the metering of the upstream ramps on the intersecting freeway may not provide the desired level of control for the managed freeway as the ramps immediately upstream of the interchange would generally make a lower traffic contribution to the turning flows at the interchange. The metering of upstream ramps on the intersecting freeway would also disadvantage traffic that is not exiting to the managed freeway. In this situation ramp signals on the freeway-to-freeway ramp would generally be required for effective control of entering flows at the interchange merge as well as control of the downstream section of managed freeway.

Entry ramps near interchange may not contribute significantly to flows exiting to managed freeway

Exiting traffic may originate over significant distance upstream

May need metering signals to effectively manage the merge and downstream section of freeway

Figure 4.3: Traffic Flows at Freeways that Cross
Managed freeways are generally only effective when traffic is controlled at all points along a route. Effective control of traffic density, particularly critical bottlenecks, means that control needs to be provided close to where problems are likely to occur. A freeway ramp meter should be controlled when analysis indicates the critical freeway bottleneck(s) is at the freeway-to-freeway entry ramp and/or in the downstream sections of freeway (e.g. within 6 or 8 interchanges of the freeway entry ramp).

If the analysis shows that it is not necessary for the freeway entry ramp to be controlled consideration should be given to:

- Using unmanaged freeway capacity values for the capacity analysis on the freeway section downstream from the uncontrolled ramp, i.e., a maximum flow of 1,800 pc/h/lane.
- Ensuring a continuing added lane is provided to increase capacity on the downstream section of freeway.
- Providing geometric controls to limit the freeway-to-freeway ramp flow to the available mainline capacity downstream, e.g., providing a single added lane to limit flows to about 1800 veh/h, rather than providing an added lane plus merge (two lanes at the ramp nose). This would reduce turbulence associated with merging and provide an effective ‘cap’ on the entering flow.

The provision of metering at upstream arterial road entry ramps compared with metering at an entry ramp from an intersecting freeway requires an understanding of travel patterns or typical trip lengths on the freeway. The traffic implications need to be analysed and this may involve an origin-destination study of the freeway trips associated with traffic entering the managed freeway from the intersecting freeway.

Safety is a prime consideration when considering the metering of a freeway to freeway ramp. Section 6.4.5 provides further guidance relating to typical arrangements for the layout of traffic management devices.

4.5. Designing for Future Retrofitting Ramp Signals

In the design of new freeways or ramps that do not meet the criteria for the provision of ramp signals within the 10 year timeframe, it can be beneficial to incorporate future provision for ramp signals that are likely to be retrofitted. This may be desirable in an urban growth area.

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 (7.0 m) with interim marking of a single lane and shoulder
- The provision of full depth pavement under shoulders to provide for future traffic when an additional lane is marked
- Entry ramp lengths (minimum 420 m from ramp entrance to physical nose) to provide for future storage (up tp 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 freeway 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.
- For higher entry flows consider future ramp widening / lengthening to suit three or four lane layouts.
Chapter 5
Freeway Traffic Data
5.1. Traffic Data Quality and Availability
The key to effective management of a freeway is reliable and accurate traffic data at appropriate locations. The traffic detection system needs to be dependable to obtain information for a range of uses.

5.1.1. Real Time Traffic Data
Real time traffic data of actual traffic conditions is essential for the effective dynamic management of freeway flow, i.e., 'If you can’t measure it, you can’t manage it.'

Real time data enables:
- Proactive management of the freeway to prevent flow breakdown
- Reactive responses to incidents or other factors that may be beyond the control of the system or operator
- Provision of traveller information, particularly for travel time and congestion.

5.1.2. Historical Traffic Data
Analysis of historical traffic data provides an understanding of traffic flow efficiency and operational problems. Evaluation of data can also assist in project development.

Historical traffic data facilitates analysis relating to:
- Traffic performance over an extended period
- Identification and evaluation of traffic problems
- Targeting and developing improvements
- Evaluation of benefits for recommended improvements
- Preparing a business case to justify funding, i.e., 'If you can’t measure it, you can’t justify it.'

5.2. Freeway Data Stations

5.2.1. Data Station Locations
The following principles for locating data stations should be applied to urban freeways to facilitate historical and/or real time use of data. On freeways where ramp metering is not provided, the appropriate positioning of data stations, generally as shown in Figure 5.2, can facilitate retrofitting at a later date.

Data stations should be installed on the mainline to cover the full length of the freeway with detectors provided in all lanes at each point. This would generally include the following locations:

a) Near Entry Ramps:
- At the end of the ramp merge, generally 320m downstream of the nose for a single lane merge. This is the primary mainline site for ramp metering control.
- Just upstream of the ramp nose with separate detectors for the ramp and mainline traffic.

b) Near Exit Ramps:
- Just downstream of the exit ramp nose, with separate detectors for ramp and mainline traffic.

c) At Other Mainline Locations:
- Potential bottleneck locations where traffic flow needs to be managed, such as just downstream of lane drops, on steep upgrades, tight curves and carriageway narrowing, e.g., no shoulder, narrow lanes or at bridges
- Remaining locations typically to ensure not more than 500m spacing along the full length of the freeway.

Power supply and communications are required at data station locations and the preferred arrangement is to provide longitudinal conduits for power and optical fibre. Alternatively, solar power and radio communications are options that can be considered.
5.2.2. Detector Accuracy and Reliability

Reliable and accurate freeway traffic data needs to be collected from the roadway. This is to provide general traffic information, to drive numerous real time traffic management systems and to provide detailed traffic information for analysis and reporting of road system performance. Because of the numerous end-users of historical data, (e.g., Austroads performance measures, network planning, road design, pavement design, traffic control and traveller information), it is important to ensure that the source data is fit for end-user purposes.

Coordinated Ramp Metering, for example, has very stringent requirements for the Vehicle Occupancy measurement in order to precisely control the freeway performance near critical flows. Therefore an absolute error greater than ±5% in a 20 second period, cannot be tolerated in the vehicle occupancy measure for effective motorway control.

Freeway traffic data comprising speed, volume and vehicle occupancy must be suitable to provide for system operation. Real time operations of managed freeways currently require vehicle data to be delivered at 20 second intervals and possibly at lower intervals in the future. Vehicle classification information is also important.

These source traffic data requirements are independent of the end-to-end service delivery and availability requirements, which for managed freeways, travel time and TMC functions, should be 95% or higher to enable automated system response capabilities. This availability also means that motorists can be provided with optimum capacity and day to day reliability.

Source data types e.g., speed, volume, occupancy (SVO) and vehicle classification, and their accuracy need to meet basic requirements to support VicRoads business needs. Source traffic data performance requirements for vehicle detection are as follows.

- Measure all freeway lanes and ramps for speed, volume, occupancy and length classification with a variation of accuracy between all lanes not more than ± 2%.
- Transmit the traffic data to control systems at interval no greater than 20 seconds.
- Record vehicle by vehicle data for volume and length classification.
- Traffic flow fundamental diagrams should be reproducible from the SVO data. This is possible from existing in-pavement technologies e.g., loop and stud technologies, however, alternate technologies may need to include vehicle classification data in their calculations as vehicle length significantly affects lane occupancy.
- Measure accurately during all weather and light conditions applicable to the route/location, e.g., tunnels, and tested in wet weather and at night to confirm ground truth, e.g., manual counting from video.
- Undertake vehicle volume counts with an accuracy of ±2% measured over 24 hours and ±3% during peak periods when lane flows are above 1,800 vehicles per lane; measured against ground truth, e.g., manual counting from video.
- Accurately measure individual vehicles under congested conditions or queuing at vehicle spacing in the order of 7 metres (gaps as low as 3 metres), e.g., when mainline vehicles are closely spaced during flow breakdown or in slow moving ramp queues.
- Undertake speed measurements in km/h with an accuracy of ±3% for speeds between 0 and 160 km/h.
- Measure vehicle length in metres with an accuracy of ±5% and logging into 4 length user-defined classification bins, for example as follows:
  - > 0 - < 6m
  - > 6 - <12.5m
  - > 12.5 - < 17.5
  - > 17.5 m.
- Measure vehicle occupancy per traffic lane with an accuracy of ±5%; vehicle occupancy must respond to changes in vehicle length.
5.2.3. Wireless Vehicle Detectors

Wireless vehicle detectors provide accurate and reliable data for presence and movement of traffic and are suitable for mainline detection and for ramps. Data transmission from the battery powered detector to a field processor occurs via an access point within 50m of the detector or, for distances up to 300 metres, by relay to the access point using a battery powered repeater point.

Installation is less intrusive compared with loops as the detector and repeater point devices do not require saw cutting, conduits/pits or cabling. The detectors, which are approximately 75mm x 75mm x 50mm in size, are installed in the pavement with a 100mm hole cutting machine and then covered with epoxy as shown in Figure 5.1.

Details of the detector layout for a wireless data station are shown on Standard Drawing No. 541701 in Figure 5.2. Prior to installation each detector is pre-configured for a specific lane and location. The detector footprint has a default setting of 600mm x 1200mm but is variable in the software and can be changed after installation. The ability to set a small footprint overcomes problems of undercounting by loops mentioned in the Note below.

![Wireless Vehicle Detector Installation](image)

*Figure 5.1: Wireless Vehicle Detector Installation*
Figure 5.2: Freeway Data Station using Wireless Vehicle Detectors
5.2.4. Detector Loops

The data station loops are installed by saw cutting the pavement. The detector includes a double loop arrangement in each lane of the freeway or ramp. Details of the loop layouts are shown on Standard Drawing TC-2033 in Figure 5.5.

**Note:**

VicRoads current practice is to use wireless vehicle detectors on ramps for queue management as part of the HERO system. The initial installation of ramp meters on Melbourne’s freeways used SCATS loops on the entry ramps. These loops which are 4.5 metres long were found to lack accuracy at low speeds as shown in Figure 5.4. The accuracy problem of SCATS loops has previously been identified by Akcelik et al (1999) where it was recommended that consideration be given to using 3.5 metre loops for through lanes and 3.0 metre loops for right turn lanes.

![Figure 5.3: Freeway Data Station Loops](image)

**Figure 5.3: Freeway Data Station Loops**

![Figure 5.4: Example of Undercounting by SCATS Loops on an Entry Ramp](image)

**Figure 5.4: Example of Undercounting by SCATS Loops on an Entry Ramp**
Figure 5.5: Freeway Data Station using Loop Vehicle Detectors
5.2.5. Traffic Data to be Collected

The principal types of data available from data detectors are:

- Flow (traffic volume)
- Speed, and
- Lane occupancy.

The data stations collect the data using a 20 second sampling period. Generally, this data is then aggregated into 1, 5 or 15 minute periods for analysis. The density of traffic (vehicles/km) can be calculated from the flow and speed data as shown in Appendix E. The lane occupancy data is generally used as a surrogate for density in relation to operational performance as it is easier to measure.

The data stations are also able to provide information related to vehicle length for vehicle classification studies. Loop detectors collect the data when activated for a specific survey. Wireless vehicle detectors are capable of collecting vehicle length data continuously.

5.3. Data Analysis Tools

5.3.1. Freeway Analysis Tool (FAT)

The VicRoads Freeway Analysis Tool (FAT) has been developed to facilitate assessment of the data from the freeway data stations. Lane data may be analysed in individual lanes or aggregated. An example of output is shown in Figure 5.6.

![Figure 5.6: Example of Chart from Freeway Analysis Tool](image-url)
5.3.2. F1RM Tool

The F1RM Tool developed by VicRoads is a versatile tool to facilitate the analysis of 1 minute freeway flow data. Examples are shown in Figure 5.7 to Figure 5.11. Other examples are used throughout the Handbook to demonstrate various traffic flow characteristics.

Figure 5.7: Contour Plot (Time / Distance / Speed) along a Route showing 6 weeks of Peak Period Speed Data to Compare Flow from Day to Day

Figure 5.8: Contour Plot (Time / Distance / Speed) of Flow along a Route on a Specific Day
Figure 5.9: Flow Characteristics at a Specific Site

Figure 5.10: Fundamental Diagrams at a Specific Site. The Data may be Viewed in Short Time Slices to Observe the Sequence of Events
5.3.3. STREAMS Data Outputs

The STREAMS system that forms the platform for VicRoads freeway management system provides a number of outputs to view data and facilitate analysis. An example is shown in Figure 5.12.

Figure 5.12: Bar Graphs of Operation in Real Time (Speed, Flow or Occupancy)

5.3.4. Spreadsheet and Charts

Data may be exported from the database and used in a spreadsheet for specific analyses, e.g., to plot a three minute moving average trend line. Examples of spreadsheet analyses are shown in Figure 5.13 and Figure 5.14.
Figure 5.13: Examples of Analysis with Raw (20 sec) Flow Data and smoothed 15 minute average

Source: VicRoads 20 October 2008
5.4. Data Analysis and Interpretation

The correct interpretation of data is essential in properly identifying the location and nature of traffic problems and in understanding the differences between symptoms and causes. A correct appreciation of the issues is also necessary to identify appropriate improvement actions. The examples provided throughout this handbook endeavour to provide guidance in data interpretation as well as appropriate analyses.

The appropriate collection and use of data for fine tuning and ongoing operation of a freeway ramp metering system is also essential for efficient, effective operation.
Chapter 6
Design of Ramp Signal Installations
6.1. Overview of the Design Process

The main components of the ramp signal design process at an entry ramp are capacity analysis, ramp storage design and then developing the design plan showing the ramp layout geometry and location of devices. The main components of the design process are summarised in Figure 6.1. The design at each ramp generally follows an investigation along the freeway to understand freeway performance and to identify potential bottlenecks along the route that affect traffic flow and capacity.

**Figure 6.1: Design Process Overview**

**Note:**

There are examples where ramp signals were installed on freeway ramps and then did not meet operational objectives due to poor design, inadequate detailed analysis and/or understanding of ramp metering principles. Performance problems may involve producing no benefits or producing adverse effects. A good control algorithm may not be able to compensate for an installation with inadequate design.
6.2. General Approach

A system approach with an investigation along a significant length of freeway is desirable to gain an overall understanding of freeway performance, infrastructure characteristics and traffic flow issues affecting the design of improvements. The investigation for upgrading of an existing route should include collection of data, data analyses and on-site observations to determine:

- The mainline and entry ramp flows at all entry ramps including locations of critical bottlenecks due to merging traffic
- Bottleneck locations due to other geometric features which may be at lane drops, steep upgrades, tight curves, width restrictions or sight restrictions
- Areas with weaving movements or significant lane changing
- Exit ramps where queues over-spill into the through carriageway. This problem cannot be treated with ramp metering and requires consideration of other improvements to avoid counteracting the planned benefits of ramp metering
- The possible emergence of new critical bottlenecks after the planned ramp metering installation, e.g., the increased throughput at a bottleneck being treated by ramp metering may trigger a new active bottleneck further downstream.

The metering rate and storage requirements at an entry ramp will vary according to the freeway 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 capacity and functional geometric layout of the ramp so that satisfactory operation is achieved after the ramp signals are installed. Consideration also needs to be given to the capabilities and operational needs of the proposed algorithm that will control the signals.

The capacity and storage analyses 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.

For design information not provided in this Handbook, refer to the VicRoads road design guidelines, the Traffic Engineering Manual Volumes 1 and 2 and the Austroads guidelines, as appropriate.

**Note:**

While capacity analysis in the design process generally focuses on traffic volumes, in operation the dynamic ramp signal system uses occupancy to optimise freeway flow.

6.3. Capacity Analysis and Storage Design

The analysis of data to determine design flows, the number of lanes at the stop line and the ramp storage needs is an essential first step in the overall design process. The preparation of signal plans without this analysis can lead to inadequate infrastructure or ineffective operation.

6.3.1. Freeway and Ramp Design Flows

A system approach along the route considering all ramps is desirable to determine the locations of critical bottlenecks that will enable the maximum entry flows to be determined at specific locations in a coordinated system. The overall objective of the analysis is to ensure that flow breakdown will not be triggered due to satisfying excess demand, i.e., in some locations provision can only be made for traffic entering the freeway without causing flow breakdown, rather than satisfying the entry ramp demand.

The design flows to be used for the entry ramp and the freeway need to be estimated then checked against the capacity of the associated merge point and any other potential downstream bottleneck. The ramp flows are also used to determine the number of lanes to be provided on the entry ramp at the stop line and the length of storage for queued vehicles. The objective is to confirm that the entry ramp design flows can be accommodated by the mainline design flow and that the likelihood of flow breakdown is minimised under the expected operation.
Satisfying the ramp demand flow is the desirable situation. In cases where the entry ramp demand flow cannot be accommodated within the freeway bottleneck capacity, the metered entry ramp flow could be less than the demand flow and would result in significant queuing and possible trip diversion.

A coordination group of ramps within a system for the purpose of design may need to extend upstream from the critical bottleneck for up to 10 entry ramps. Within a coordination group the locations where entry flows need be restricted or balanced across a number of adjacent ramps may need to be identified.

6.3.1.1. Upgrading of an Existing Freeway or a New Ramp / Freeway

Freeway and entry ramp demand flows may be determined by considering factors such as:

- Capacity increases for an upgraded freeway
- Current traffic demands and travel patterns adjusted according to appropriate traffic growth trends and likely changes to travel patterns
- Traffic generation of areas serviced by a new ramp
- Traffic modelling of the new/upgraded road network links.

6.3.1.2. Existing Freeway

Peak period traffic flows need to be determined for each entry ramp under consideration as well as the freeway mainline flow at each interchange and critical bottleneck. To determine an entry ramp design flow, the following data collection and analysis is generally required.

1. Assess traffic flow data during each peak period for the freeway direction under consideration to determine:
   - Current entry ramp flow and flow profile, and
   - Freeway flow at the interchange immediately upstream of the entry ramp, i.e. between exit and entry ramps within the interchange.

   Note: This information is available from freeway data stations or a specific traffic survey. Alternatively, the freeway flow and profile at the merge can be calculated from:
   - Freeway flow upstream of the interchange, and
   - Subtracting the exit ramp flow.

2. Assess freeway flow data (flow, speed and occupancy) to determine if flow breakdown is occurring during peak periods at:
   - The entry ramp merge points, or
   - Any other downstream bottlenecks, e.g., tight curves, steep upgrades or high weaving areas.

   If flow breakdown is occurring, the peak period raw traffic data may mask the true demand, particularly if the freeway breaks down for an extended period. In such cases the designer may need to use the flow rate during the brief period prior to breakdown then apply an appropriate peak hour factor (PHF) to determine the true hourly design flow.

   Note: On existing freeways examining flow data at 15 minute intervals provides a preliminary indicator to identify the periods where flow breakdown occurs. To examine the locations and probable causes of flow breakdown, one minute data generally provides the detail required during the unstable periods.

3. Determine the critical bottleneck location for the section of freeway, based on information gained in Step 2.

   Note: The critical bottleneck along the route, i.e., where flow breakdown first occurred, can generally be identified from a FIRM tool plot.
6.3.2. Ramp Demand Relative to Mainline Capacity

When the freeway and ramp flows have been determined the following steps aim to compare the ramp demand flow with the capacity of the freeway at the downstream bottleneck location.

1. Determine the design capacity, q_{cap} at the freeway critical bottleneck (merge or downstream bottleneck). This is determined by an assessment of the flow at which flow breakdown is expected to occur. Figure 6.2 shows the parameters involved and for the purpose of analysis, the bottleneck design capacity would generally be:
   - A maximum of 2,100 pc/lane/h averaged over all freeway lanes, assuming favourable freeway mainline conditions, or
   - A lower value if geometric factors affect capacity at the merge or downstream section of freeway before the next exit, e.g., steep grade or tight radius curve, or
   - Where existing flow data is available, generally 95% of the 5 minute flow prior to breakdown, assuming free flow conditions before capacity flow is reached, i.e., the site is a critical bottleneck and that flow breakdown is not due to a shockwave from downstream – refer Section 2.3.2.

2. Compare the maximum entry ramp flow that is able to enter the freeway, q_{r}, with the ramp arrival (demand) flow, q_{ra}, i.e., the design flow is to match the capacity of the bottleneck at the merge or other downstream bottleneck (refer Section 3.4.1).

3. Where a comparison of maximum metered volumes at a ramp with the arrival flow identifies a location where ramp demands may not be accommodated, consideration should be given to:
   - The potential for redistribution of some traffic to other routes. The implications of unsatisfied demand require an assessment of the arterial road network to determine possible routes for traffic diversions within the arterial road network, e.g., for short trips, or for diversion to another freeway entry ramp which is likely where longer trips may be involved. An adjustment of entry ramp flows at a particular location may result in an acceptable design where trip diversion is feasible. In this situation it may be necessary to modify the signal phasing at the arterial road/entry ramp intersection to encourage trip diversion. Many parts of arterial road networks are generally relatively permeable and can disperse congestion. In some instances the arterial roads may also have sufficient capacity to accommodate redistributed traffic.

---

**Note:**

Although a notional capacity is used in the initial design, in operation the ramp metering system will endeavour to optimise flow by controlling occupancy.

![Figure 6.2: Entry Ramp Capacity Analysis](image)
- The provision of real time information signs to display travel time information to assist drivers in making a route choice (refer Section 6.4.12.3)
- Providing for ramp queue overflow onto the arterial road (refer to Section 6.3.5 and Section 8.2)
- Also metering upstream ramps, if this matter is encountered at a proposed isolated ramp meter installation
- Increasing downstream freeway capacity.

6.3.3. Number of Traffic Lanes at the Stop Line

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

\[
c_r = \frac{3600 \times \text{No. lanes at the stop line} \times \text{No. veh/g/l}}{q_{ra}}
\]

Equation 6-1

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

On high demand freeways, the desirable minimum cycle time adopted for design and capacity analysis averaged over the design peak hour should typically be in the order of 7.5 seconds for one and two lane ramps. For three or four lane ramp meters with an added lane, 6.5 seconds is a typical minimum average value over the design hour. These average cycle time values over the design hour allow for real time operational flexibility. In practice, as outlined in Section 7.5.2 and as shown in the example in Figure 6.3, longer and shorter cycle times will occur within the dynamic system over the peak period based on traffic conditions at the bottleneck and coordination relative to other ramps. If a cycle time in the desirable range cannot be achieved in design, this may result in ineffective metering of ramp demands during operation.

![Figure 6.3: Example of Average and Varying Cycle Times](image)

Figure 6.3: Example of Average and Varying Cycle Times

Cycle times lower than 7.5 seconds (6.5 seconds for three and four metered lanes) as shown orange in Table 6.1, could be appropriate when the capacity analysis indicates ramp demands are accommodated with spare capacity on the mainline, e.g., where there is low mainline flow or an added lane.

Designs with average cycle times outside the limits in Table 6.1 shall be approved by the Executive Director – Policy and Programs.
### Indicative layout (5)

<table>
<thead>
<tr>
<th>Ramp Design Flow (5)</th>
<th>Total Storage Required (Lane metres)</th>
<th>Ramp Storage (3) and Cycle Time (7) relative to the number of lanes at the Stop Line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lane</td>
<td>1 Lane</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single lane merge (6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>113</td>
<td>113</td>
</tr>
<tr>
<td>300</td>
<td>170</td>
<td>170</td>
</tr>
<tr>
<td>400</td>
<td>227</td>
<td>227</td>
</tr>
<tr>
<td>500</td>
<td>283</td>
<td>283</td>
</tr>
<tr>
<td>600</td>
<td>340</td>
<td>340</td>
</tr>
<tr>
<td>700</td>
<td>397</td>
<td></td>
</tr>
<tr>
<td>800</td>
<td>453</td>
<td></td>
</tr>
<tr>
<td>900</td>
<td>510</td>
<td></td>
</tr>
<tr>
<td>1,000</td>
<td>567</td>
<td></td>
</tr>
<tr>
<td>1,100</td>
<td>623</td>
<td></td>
</tr>
<tr>
<td>1,200</td>
<td>680</td>
<td></td>
</tr>
<tr>
<td>Added lane entering the freeway or Two lane merge</td>
<td>1,300</td>
<td>737</td>
</tr>
<tr>
<td></td>
<td>1,400</td>
<td>793</td>
</tr>
<tr>
<td></td>
<td>1,500</td>
<td>850</td>
</tr>
<tr>
<td></td>
<td>1,600</td>
<td>907</td>
</tr>
<tr>
<td></td>
<td>1,700</td>
<td>963</td>
</tr>
<tr>
<td></td>
<td>1,800</td>
<td>1,020</td>
</tr>
<tr>
<td>Added lane entering the freeway plus a merging lane</td>
<td>1,900</td>
<td>1,077</td>
</tr>
<tr>
<td></td>
<td>2,000</td>
<td>1,133</td>
</tr>
<tr>
<td></td>
<td>2,100</td>
<td>1,190</td>
</tr>
<tr>
<td></td>
<td>2,200</td>
<td>1,247</td>
</tr>
<tr>
<td></td>
<td>2,300</td>
<td>1,303</td>
</tr>
<tr>
<td></td>
<td>2,400</td>
<td>1,360</td>
</tr>
<tr>
<td></td>
<td>2,500</td>
<td>1,417</td>
</tr>
<tr>
<td></td>
<td>2,600</td>
<td>1,473</td>
</tr>
<tr>
<td></td>
<td>2,700</td>
<td>1,530</td>
</tr>
<tr>
<td></td>
<td>2,800</td>
<td>1,587</td>
</tr>
<tr>
<td></td>
<td>2,900</td>
<td>1,643</td>
</tr>
<tr>
<td></td>
<td>3,000</td>
<td>1,700</td>
</tr>
</tbody>
</table>

### 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. vehs. / green / lane: 1
5. Ramp layout and ramp design flow are subject to the bottleneck capacity on the mainline (refer Section 6.2.2).
6. A single lane merge layout may be satisfactory for higher flows, e.g., a ramp flow of 1600 veh/h with mainline of 2400 veh/h on a two lane freeway mainline.
7. Cycle times lower than values in black are generally not appropriate as an average cycle over the design hour.
8. Cycle times in orange may be appropriate at ramps with spare mainline merge capacity (refer Section 6.2.3).
9. Designs with average cycle times outside the limits in this table shall be approved by the Executive Director – Policy and Programs.

### Table 6.1: Lanes at the Stop Line and Ramp Storage Requirements

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 an auxiliary lane, particularly if a long ramp provides adequate storage. Examples are shown in Figure 6.4 and the standard drawings referred to in Section 6.4.
Figure 6.4: Examples of Localised Flaring at the Stop Line for Auxiliary Lanes

**Note:** VicRoads previous ramp metering guidelines (2005), provided options for metering with 2 (or 3) vehicles per green per lane. This form of operation has not been trialled successfully in Australia, although it is used in some overseas jurisdictions with limited success. 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:

a) 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.

b) 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.

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 below. Generally, it is preferable to release a single vehicle per green per lane, even if shorter cycle times need to be adopted.

<table>
<thead>
<tr>
<th>No. veh/g/lane</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green time (sec)</td>
<td>1.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Yellow time (sec)</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Red time (sec)</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Cycle time (sec)</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Flow (veh/h)</td>
<td>1200</td>
<td>1530</td>
</tr>
</tbody>
</table>

In exceptional circumstances when 1 veh/g/l is not workable, e.g., a high flow freeway to freeway situation or where widening for auxiliary lanes is not feasible or cannot provide sufficient capacity, then 2 veh/g/l operation may need to be considered. In these circumstances, until more information is available, a design discharge rate of 1.7 veh/g/l is appropriate.

In other situations, a longer green period to release 3 or more veh/g/l, i.e., short platoons, may be an option if the ramp entry becomes an added lane on the intersecting freeway. In this case an appropriate time for the green phase is used without reference to a particular number of vehicles per green, i.e., no signs are needed.

Freeway ramp metering designs which use more than 1 veh/g/l shall be approved by the Executive Director – Policy and Programs.
6.3.4. Ramp Storage Requirements

6.3.4.1. Desirable Standard

The desirable 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. This standard shall be provided by lengthening existing ramps when it is economically feasible within design constraints, e.g. downstream bridge or exit taper. This facilitates operational flexibility to provide for the following situations:

- To limit vehicle entry to the freeway when the ramp merge or downstream freeway is at or approaching capacity
- To balance queues between adjacent ramps in a coordinated system
- To reduce the likelihood of overflow queues extending onto the arterial road
- To provide for short term variations in traffic demand within the peak period
- To accommodate traffic growth or future change in travel patterns, and
- To limit vehicle entry to the freeway during an incident and to facilitate recovery after an incident (refer Section 3.7).

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.

\[
L_{rDes} = n_{rMax-wait} \times L_{vs}
\]

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

Equation 6-2

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.

\[
n_{rMax-wait} = \frac{q_{ra} \times t_{Max-wait}}{60}
\]

Equation 6-3

If more than 4 minutes storage is available on a long ramp, this provides advantages as the additional storage will provide greater operational flexibility.

Table 6.1 provides a guide to entry ramp storage lengths to be provided for various operational arrangements on the ramp. The total storage requirement is divided by the number of lanes along the ramp to determine if adequate storage is available, or compared with the total lane length if lanes are of different lengths.

The ramp storage achieved in the design has implications for the operational management of the freeway (as outlined above), as well as the arterial network as a whole. Therefore, the storage achieved relative to the desirable guideline needs to be documented during scope approval of the project. In some instances the ramp may need to be lengthened, e.g., by extending the nose, or widened to increase storage.

6.3.4.2. Storage Difficulties

In locations where providing the desirable storage, i.e., 4 minute wait time, is not feasible, a lower storage value may need to be considered. This may be appropriate when the analysis indicates that entry ramp demand flows are satisfied (refer Section 3.5). Operational constraints are generally created if ramps have minimal storage. An arterial road network with good connectivity can facilitate re-routing of trips to adjacent ramps to compensate for a low storage ramp. Balancing of queues by the coordinated ramp signal system to ramps with surplus storage, if available, will also assist.
Therefore, where ramp storage is compromised in design, other ramps immediately upstream should be provided with at least the desirable standard and preferably more, to compensate for the loss of overall system storage. If adequate overall storage is not achieved it is to be expected that operation will be compromised.

Where the desirable standard of storage cannot be provided, consideration should be given to the implications of queue overflow into the arterial road (refer Section 6.3.5 and Section 8.2), as well as the potential for motorists to change their travel route to other ramps. In this situation, the arterial network needs to have the capacity and connectivity to provide the opportunity for motorists to change their travel patterns.

In a situation where the desirable storage cannot be provided, typically a minimum 3 minutes queue length may need to be adopted for design. This queue length between the ramp entrance and the ramp signals stop line will generally be sufficient to accommodate storage for turning vehicles arriving in a platoon from the arterial road/ramp intersection signals. However, it would restrict the system’s ability to build a queue in order to manage mainline traffic and prevent flow breakdown.

**6.3.4.3. Example of Capacity and Storage Calculations**

Capacity and storage calculations along a route can be undertaken in a spreadsheet. An example is shown in Figure 6.5.

**Figure 6.5: Example of Capacity and Storage Calculations**
6.3.5. Considering Ramp Queue Overflow onto the Arterial Road

As a general principle, freeway ramps should be designed to provide the desirable storage indicated in Section 6.3.4.1. In circumstances that prevent this being achieved, ramp overflow onto the arterial road needs to be considered. This may include:

- Consideration of improvements at the arterial road/entry ramp intersection, such as extending or providing right or left turn lanes to increase effective storage for the entry ramp traffic (refer Section 8.2)
- SCATS system integration. This may include implementation of leading and lagging right turn phases at the arterial road 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
- Provision of arterial road queue detectors (refer Section 6.4.9)
- Considering potential for trip diversion
- Considering equity between left and right turn movements into the ramp, e.g., signalising a left turn slip lane.

Section 8.2 provides further information relating to the management of ramp overflow queues.

6.4. Geometric Design and Layout of Devices

6.4.1. General Ramp Layout

The general layout of freeway ramp signals at various entry ramp configurations are shown on the Standard Drawings outlined in Section 6.4.1.2. The layouts in the standard drawings are based on the geometric standards for freeway entry ramps in VicRoads road design guidelines. 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 needs to be checked to ensure the overall design is satisfactory and meets current design standards.

The number of lanes to be provided at the stop line and the storage length for vehicles are based on analysis as described in Section 6.3.

6.4.1.1. 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 distance. This provides greater flexibility in operation when the freeway is experiencing congestion (refer Section 6.3.4).

In situations where increased storage is needed, consideration may need to be given to extending the ramp nose together with extending the length of the overall merge length to maintain the desirable standards.

The stop line location 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. Separated decision making points are provided where multiple merge manoeuvres are required
- 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.
6.4.1.2. Standard Drawings

The general layout of freeway ramp signals at various entry ramp configurations are shown on the standard drawings listed in Table 6.2 with further details provided in Sections 6.4.2 to 6.4.5. The choice of treatment is based on capacity and storage considerations outlined in Section 6.3 as well as strategic objectives, such as the desirability of priority access lanes.

<table>
<thead>
<tr>
<th>Ramp Type</th>
<th>Drawing No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two lanes of metered traffic</td>
<td>453771</td>
</tr>
<tr>
<td>Two lanes of metered traffic plus a priority lane</td>
<td>541797</td>
</tr>
<tr>
<td>Two lanes of metered traffic plus a metered priority lane</td>
<td>541798</td>
</tr>
<tr>
<td>Three lanes of metered traffic</td>
<td>541795</td>
</tr>
<tr>
<td>Four lanes of metered traffic</td>
<td>541796</td>
</tr>
<tr>
<td>Freeway to freeway interchange</td>
<td>453912</td>
</tr>
</tbody>
</table>

Note: Electronic copies of the drawings for printing in A3 size are available:

Table 6.2: Standard Drawings for Freeway Ramp Signals

6.4.2. Two Lane Entry Ramp (Drg. No. 453771)

The typical entry ramp layout for a ramp with two metered lanes is shown in Figure 6.6. The layout for two lane ramps is the general minimum for entry ramps. However, a similar layout would be adopted for low flow ramps only requiring a single lane.

For two lane ramps, the stop line is generally located 80 metres upstream of the ramp nose. When the signals are operating, this distance aims to maximise ramp storage while still providing an overall acceleration and merging distance of 400m (80m plus the standard 320m entry lane merge distance) which is sufficient distance for cars to accelerate from 0 to 80 km/h when merging with the left lane of the freeway. For grades of 5 or 6% the acceleration distance includes part of the final merge taper.

A speed of 80 km/h in the left lane of the freeway is appropriate for merging during periods of high flow when the ramp meters are operating. This figure is also consistent with the speed threshold used for activation of the ramp signals. Based on the operation of current ramp signals installed, the above standard has been satisfactory for trucks. Nevertheless, on ramps with high truck volumes a greater merging distance could be considered as indicated below.

The stop line location also provides satisfactory operation for the two lanes to one lane taper before the nose when the signals are not operating. When the signals are off, 80 metres provides adequate distance near the end of the ramp for ramp traffic travelling at 80 km/h to merge to a single lane before the nose, based on the standard for an acceleration lane merge (1m/s lateral shift). Further acceleration to match the speed of traffic in the main carriageway can then be undertaken.

The stop line distance 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
- 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, or
- On long high standard ramps that may operate at high speeds.
Figure 6.6: Typical Freeway Ramp Signals Layout - 2 Metered Lanes
6.4.3. Priority Access Lanes

To provide an access advantage to selected vehicles, an additional entry ramp lane may be installed to allow those vehicles to bypass the ramp queue. An example providing truck priority is shown in Figure 6.7.

A 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 freeway operational speeds on uphill grades

- Vehicles occupied by more than one person such as buses, taxis or specified high occupancy (HOV) vehicles, e.g., a Transit Lane to provide priority and incentive for people to share vehicle usage. Motor bikes may also use Transit Lanes;

- Public transport priority where the entry ramp is part of a bus route.

With appropriate regulatory signing as outlined in Section 6.4.13, a priority lane is enforceable under Road Safety Road Rules 2009 (Rules 154, 156, 157 and 158).

Where a freeway is managed to optimise traffic flow, maximum utilisation of the mainline infrastructure is provided to keep all lanes operating efficiently and in reducing overall trip times. Therefore, when compared with the use of a dedicated priority lane on the mainline that is generally underutilised, the use of priority access lanes on an entry ramp, in association with freeway entry ramp signals to manage flow on the mainline for all vehicles, is an effective option for maximising the use of the freeway.

The types of bypass lanes include:

- Free flow bypass lane. These lanes provide an uncontrolled movement of priority vehicles along the ramp and avoid the need for vehicles to stop. However, the uncontrolled entry flow can cause problems for management of the mainline when there are heavy freeway demands. Therefore, uncontrolled free flow bypass lanes should only be used in the absence of a critical bottleneck in the downstream sections of the freeway.

- Partially controlled / free flow bypass lane. In the context of managing freeway flow it is generally preferable to control all entry flows. This priority lane operation has a free flow bypass lane which is controllable with ramp signals that switch on separately to the general traffic ramp signals. This arrangement has the advantage of only activating the bypass lane signals when the freeway is approaching a high level of occupancy. The bypass operates as an uncontrolled / free flow lane when traffic conditions permit, e.g., when the freeway is below capacity and ramp queues are under control, and then the lane operates as a controlled bypass during times of critical mainline flow management. This layout has the same geometry as a free flow bypass lane.
Controlled by metering signals. Although priority vehicles are metered, the separate priority access lane provides an advantage as the queues will be shorter for the priority lane. Preference should be given to providing metered priority access lanes or partially controlled bypass lanes rather than full time free flow access. This improves freeway control and maximises the potential for sustaining desirable freeway performance.

Given the importance of ramp capacity and storage, priority access lanes should only be provided where there is a significant strategic need 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:

1. Sites where a bus route uses the ramp
2. Ramps on the Principal Freight Network (PFN)
3. Other ramps not on the PFN but with high truck volumes
4. 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
5. 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.

6.4.3.1. Freeflow and Partially Controlled Priority Lane (Drg. No. 541797)

The freeflow priority lane layout has advantages that the priority vehicles do not need to stop then accelerate to merge, and the geometry is suitable for use at all times, i.e., when the signals are operating and not operating. The freeflow priority lane layout requires a second merge distance when entering the mainline and may involve more extensive road works when compared to a metered priority lane layout.

A disadvantage of a free flow priority lane is that there is reduced control over the volume of traffic entering the freeway and hence the ability to manage flow at the mainline bottlenecks. However, the ramp metering algorithm does consider the bypass traffic at the bottleneck and may reduce the metering flow rate for other traffic accordingly. Therefore vehicle detectors are provided in the priority lane as shown in the standard drawings. A partially controlled access lane provides control when necessary.

The entry ramp layout for ramp with a free-flow priority bypass lane is shown in Figure 6.8. The geometry is based on the following design principles:

1. The stop line is 80m from the nose for the two vehicles leaving the stop line to merge
2. A separation (generally 0.7m) is provided between the bypass lane and the metered vehicle lane. This separation tapers to a single line over the 80m merge distance
3. The distance of 180m from the nose to the start of the bypass merge taper is consistent with the standard merge length from the nose to start of the merge taper. This distance allows vehicles to merge with the freeway traffic or choose to stay in the auxiliary lane and allow bypass vehicles to merge
4. The 140m bypass lane merge taper is the standard freeway merge length
5. 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
6. The 140m final merge taper is the standard freeway merge length
7. Kerb and channel is provided over the total distance of 560m available for the merging movements downstream of the ramp nose to minimise formation width, i.e., with no shoulder. The shoulder develops over the final 140m taper to match into the existing freeway shoulder.
6.4.3.2. Metered Priority Lane (Drg. No. 541798)

A metered priority lane is appropriate under the following circumstances:

- If the freeway management requires that all entering traffic is controlled, or
- If insufficient space is available on the freeway for the unmetered merge length, e.g., if the start of an exit ramp taper is immediately downstream.

Although the priority lane is metered, generally the priority vehicles would still have the advantage of a shorter queue and less delay entering the freeway.

The typical entry ramp layout for ramp with a metered priority bypass lane is shown in Figure 6.9. The stop line with this layout is located 150m from the ramp nose to provide additional merge distance for the three to one lane merge. A disadvantage of the metered bypass layout is reduced storage on the ramp compared with a setback of 80m from the stop line with no priority lane, unless the ramp is lengthened by extending the nose.

With the metered priority lane layout, the priority lane is a part-time lane and not suitable for operation when the metering signals are not operating, i.e., the merge lengths downstream of the stop line are inadequate for merging at higher operating speeds when the signals are off. Lane control signs are provided to restrict use of the priority lane outside metering times.
Figure 6.9: Typical Freeway Ramp Signals Layout - Metered Priority Lane
6.4.4. Three and Four Lanes at the Stop Line (Drg. Nos. 541795 & 541796)

The typical entry layouts for ramps with three metered lanes and four metered lanes at the stop line are shown in Figure 6.10 and Figure 6.11 respectively.

Ramp layouts with three lanes at the stop line require greater distances between the stop line and the nose for the merging movements, particularly if three lanes need to merge to 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 an auxiliary lane at the stop line (part time use when the signals are on). If two lanes are provided at the nose, i.e., two lane merge onto the freeway 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.

The metering layouts with four lanes at the stop line require a distance of 120m between the stop line and ramp nose. 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.

6.4.5. Freeway to Freeway Ramp Metering (Drg. No. 453912)

The principles for managing freeway to freeway (system interchange) ramps are outlined in Section 4.4.

A typical layout for the freeway ramp signals is shown in Figure 6.12 for situations where freeway to freeway entry ramps are to be metered. There can be significant challenges related to ramp metering of freeway to freeway ramps including presence of structures and widening of embankments. There are also operational implications due to managing high traffic flows, balancing queues and delays between ramps, providing the storage required and safety. The detailed layout and geometry for the ramp signals would be developed according to the standard drawings for two, three or four lanes, as appropriate.

Drawing No. 453912 indicates the following two options for the location of the ramp signals:

a) Using separate 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

b) Using a single stop line downstream of the merge between the two ramps after they form a single entry ramp onto the intersecting freeway. With this option there needs to be adequate storage within the interchange between the ramp signals and the merge of the upstream ramps.

RC2 warning signs are provided near the start of the ramp to warn drivers when ramp signals are operating. Consideration may also need to be given to freeway VMS prior to the ramp exit for purposes of incident management and ramp closure.

Where the ramp’s design speed is greater than 60 km/h, a variable speed limit sign would generally be appropriate. Generally, a 60 km/h speed limit would operate throughout the metering period. It is desirable for the variable speed limit signs to be capable of displaying speeds between 40 and 100 km/h.

The initial variable speed limit sign is generally located just after the exit ramp nose on the turning roadway being metered. The speed limit would generally terminate immediately after the metering signals to enable the merging vehicles to accelerate to the speed of the freeway they are entering. The variable speed limit within the interchange terminates with the speed limit or the variable speed limit operating on the intersecting freeway.
CHAPTER 6 DESIGN OF RAMPSIGNAL INSTALLATIONS

Figure 6.10: Typical Freeway Ramp Signals Layout - 3 Metered Lanes

THREE LINES TO ONE LANE AT NOSE - MERGE

CONTINUOUS THIRD LANE ON APPROACH OR PARALLEL FLARED LENGTH >30m

LOCALISED FLARING AT STOP LINE

THREE LINES TO TWO LINES AT NOSE - ONE MERGE PLUS ONE ADDED LANE

LEFT-SIDE FLARE OR CONTINUOUS THIRD LANE

SIGNAL GANTRY

GENERAL NOTES
1. THE LANE/ LANE OUTSTREAM FROM THE NOSE IS ISSUED ON THE INCREASED TREATMENT.
2. LINES TO THE ROAD DESIGN LINES - LANE 3 PLAYS THE MORE WITH.
3. LINES TO TRAFFIC ENGINEERING MANUAL VOL. 3 FOR SIGN AND PURPOSE INCENTIVE.

FINISHED DRAWING: 3 LINES METERED

MERGE LAYOUTS
FREEWAY RAMP SIGNALS
3 LANES METERED
Figure 6.11: Typical Freeway Ramp Signals Layout – 4 Metered Lanes

FOUR LANES TO TWO LANES AT NOSE - ONE MERGE PLUS ONE ADDED LANE

EXTENDED FLARE OR CONTINUOUS APPROACH LANES

POSITION OVER CENTRE OF LANE TWO

POSITION OVER CENTRE OF LANE THREE

LOCALISED FLARE BOTH SIDES

SIGNAL GANTRY
CHAPTER 6 DESIGN OF RAMPS SIGNAL INSTALLATIONS

Figure 6.12: Typical Freeway Ramp Signals Layout – Freeway to Freeway Ramps
6.4.6. Controller Location

The controller location should be 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 arterial road as well being relatively close for viewing of the ramp control signs. This location is also convenient for providing a pole near the arterial road to be used for a CCTV camera and the wireless detector access point (refer Sections 6.4.11 and 6.4.15).

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 freeway carriageway is generally undesirable.

6.4.7. Signal Pedestals

The signal support pedestal is installed adjacent to the ramp 10 metres downstream of the stop line. The use of a joint use mast arm (JUMA) is the usual standard for 2 lane ramps. The use of a JUMA facilitates fixing of detector and CCTV devices. The use of a 9m JUMA is generally adequate, however, 11m or 13.5m poles may need to be used if additional height is required for reception and/or transmission of detector data, e.g., when line of transmission is obscured by trees or structures.

The use of 2B pedestals each side of the ramp as shown in Figure 1.1 have also been used successfully and may be considered at sites where a JUMA 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 including installations with priority access lanes. The design for the freeway ramp signals gantry structure is available on VicRoads standard drawings. Where overhead lanterns are provided on a JUMA 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 (JUMA, 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 JUMA is that it only results in guard fence on one side of the ramp. Where a pole needs to be located on the freeway side of the ramp, consideration should also be given to the need for a safety barrier on the side adjacent to the main carriageway.

6.4.8. 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 outreach and ramp width involved, a lantern would generally be provided for each lane on the JUMA outreach or on the gantry as indicated on the drawings. Where 2B pedestals (or JUP plus a 2B) are used, the upper lanterns shall be installed in the high mount position (2920mm high).
Note: Although only one low mounted signal faces drivers in some layouts, e.g., on a JUMA or on the gantry leg in the priority access lane layout, the overhead LED signal lanterns are also visible at the specified stop line distance from the signals and meet the luminous intensity standards in AS 2144 for the driver’s viewing angle at the stop line (refer to test results in Appendix C).

The desirable layout for overhead signal lanterns is to mount the lanterns directly over each lane. It is recognised that the standard 5.5m JUMA outreach width does not enable this to be achieved, and the current angled outreach is also less than desirable. Consideration is being given to a new horizontal arrangement with increased length of outreach for the future.

On a JUMA, JUP or gantry, the lower lanterns are to be mounted at a height of 2340mm (approx. 2200mm to the underside of the target board). 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 a 2B pole are used instead of a JUMA, the lower lanterns are to be mounted at a height of 1200mm with the One Vehicle Per Green (G9-V167) and Each Lane (G9-V166) signs installed between the high mounted and low mounted lanterns.

Note: VicRoads freeway ramp signals standards for signs and signals are based on best practice which varies from earlier standards as outlined in the Austroads Guide to Traffic Management Part 10: Traffic Control and Communication Devices and AS 1742.14, particularly in relation to the use of three aspect lanterns. Anecdotally motorists’ observance of two aspect lanterns is not good. This may be because they are different to conventional 3 aspect traffic signals and drivers misunderstand the legal significance. Legally there is an advantage to provide a yellow signal because it gives some warning that a red light is coming (for which a driver must stop). Other advantages for using 3 aspect signals based on experience in Victoria include:

- It is beneficial to use a flashing yellow for the start up and close down sequence
- Public acceptance with ramp signals is very good. It is considered that this is because the signals are no different to normal traffic signals, except for the phase and cycle times
- Compliance is a key factor in the operation of a ramp metering system and therefore this alone justifies the use of 3 aspect lanterns.

6.4.9. Mainline Detectors

Detectors on the freeway mainline provide traffic data for flow, speed and occupancy to control the ramp signal system.

The freeway detectors in each lane on the mainline provide the principal sources of data for activation/deactivation and operation of the ramp signal system. The detectors are located just beyond the turbulent merging area and provide feedback to the ramp signal system to optimise freeway flow by controlling entering traffic from upstream ramps. The detectors are also used to provide speed, flow and occupancy data for monitoring freeway performance.

For entry ramps with a single lane at the ramp nose, the mainline data detectors are generally provided 320m downstream of the ramp nose, i.e., at the end of the taper. For entry ramps with two lanes at the nose, including layouts with an unmetered priority access lane, the mainline detectors are provided at the end of the final merge taper.

In an added lane situation where there is no merge, the downstream detectors are generally locating at the same distance as for a merge arrangement, i.e. 320m downstream from the physical ramp nose. This location is generally appropriate for measuring occupancy due to weaving of entering traffic and the traffic changing lanes into the added lane for leaving the freeway at the next downstream exit. This distance also provides appropriate spacing relative to the previous upstream detectors which will typically be about 100m upstream of the ramp nose.
As outlined in Section 5.2.1, freeway data detectors are also provided on the mainline upstream of the ramp nose for traffic counting and monitoring of freeway performance, e.g., for travel time and incident management. Freeway data detectors should also be provided on the freeway carriageway at about 500m spacing along the mainline between interchanges for monitoring traffic flow and management of bottlenecks. Detectors upstream of the nose can be used by the ramp signal system if the downstream detectors at the merge become unusable for any reason. Other downstream detectors, particularly at a bottleneck, can also be used by the ramp metering system.

The type of detector should be specified in the design together with locations for other equipment, e.g., repeater points (RP) and access points (AP) for wireless detectors (refer Section 5.2). Specific bottleneck locations where flow breakdown is likely to occur may need to be included for detector installation and monitoring to ensure mainline data is available at appropriate locations for the ramp metering system.

**6.4.10. Ramp Detectors**

**6.4.10.1. 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.

**6.4.10.2. Middle of Ramp Queue Detectors**

Detectors provided at the midpoint between the stop line and the ramp entrance detectors are used for queue length estimates and queue management in the ramp signal control algorithm. The mid ramp detectors are not required for an unmetered priority access lane.

Mid ramp detectors are not provided on metered priority access lanes as the bypass traffic (with short or no queue) is not considered in relation to occupancy values in the queue management part of the control algorithm.

**6.4.10.3. 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 arterial road.

The ramp entrance detectors are positioned to suit the layout of the ramp entrance. The layouts are treated differently within the control algorithm.

**Type 1**

The left turn slip lane intersects the ramp and traffic gives way to the right turn traffic. A balanced queue is formed for vehicle detection and queue management.
Type 2
The left turn slip lane and the section of the ramp for the right turn traffic form separate queues at the ramp entrance. Although lane changing may occur within the ramp, vehicle detection is in separate lanes for queue management.

For a ramp that is longer than the desirable storage from the stop line as outlined in Section 6.3, the ‘ramp entrance’ detectors are placed at the 4 minute queue distance. Other queue overflow detectors as outlined in Section 6.4.10.4 may also be provided for queue management.

6.4.10.4. Queue Overflow Detectors
Whenever possible the freeway ramp storage should be designed to accommodate the estimated storage requirements as outlined in Section 6.3.4 to avoid queues overflowing into the arterial road. When this cannot be achieved, consideration may need to be given to installing separate queue overflow 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 arterial road at the start of the right and/or left turn lanes leading to the ramp.

For a long ramp, i.e., longer than the desirable 4 minute queue storage distance, the queue overflow detectors may be installed at the ramp entrance.

Note:
An interface with the SCATS system is available to obtain information from the signal detector loops on the arterial road. The interface also enables transfer of information from the ramp detectors to the SCATS traffic signal system to enable control of the adjacent arterial road intersection signals according to predetermined control strategies.

6.4.11. 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 JUMA, 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 JUMA, 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 an accident.

6.4.12. Ramp Control Signs and Real Time Information Signs
Freeway ramp signals are part-time traffic control devices and drivers need to be advised when the signals are operating. Traveller information is also important to advise drivers of travel conditions on the freeway. Electronic ramp control signs (RC1), warning signs (RC2) and real time information signs (RC3) operate as part of the ramp signal, traveller information and incident management systems to provide the following information:
6.4.12.1. RC1 Warning and Regulatory Sign

The RC1 signs display warning and regulatory messages and are provided on the approaches to the arterial road/entry ramp intersection to face traffic turning into the ramp. ‘RAMP SIGNALS ON’ as shown in Figure 6.13 is displayed when the ramp signals are operating. The signs have a dual role and can also be activated for operation as part of freeway incident management to display ‘FREEWAY CLOSED’ and a symbolic No Right/No Left Turn, No Entry or other specified message, as appropriate.

![Figure 6.13: RC1 Sign Messages](image)

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

6.4.12.2. 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 signals ahead (static symbolic sign W3-3B sign) and electronic ‘PREPARE TO STOP’ alternating with ‘RAMP SIGNALS ON’ signs as shown in Figure 6.14.

![Figure 6.14: Entry Ramp Warning Signs with Alternating Messages](image)
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 freeway, including ramp delay, and contribute to the freeway management during periods of congestion or incidents. Examples of RC3 signs are shown in Figure 6.15 and Figure 7.4. Further information is included in the traveller information and incident management guidelines.

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 freeway conditions after a motorist enters the freeway, e.g., left lane closed. Being able to manage the freeway during events also facilitates faster recovery of the freeway after an incident.

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

- Separate signs are provided for all metered ramps in advance of the left and right turn lanes at the interchange
- When the interchange is close to a downstream freeway fork, i.e., one or two interchanges prior to the freeway dividing into two downstream routes creating a route choice, two RC3 signs are provided at each approach to enable separate displays of travel time and incident information for each downstream route
- Where an RC3 sign is not justified on an approach, e.g., due to a low traffic movement turning onto the freeway or where downstream travel time data is not available, an advanced RC1 would generally be provided on the approach to supplement the RC1 sign at the intersection.

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

**Note:**

An Instinct and Reason report prepared for Austroads (2008) relating to research on road user information needs with an emphasis on variable message signs, indicates 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 it was 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.”
6.4.13. Other Signs

Static 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 and Each Lane (G9-V198)**
  These signs are located on the signal pedestal near each lantern.

- **Form One lane (G9-15B)**
  These signs are located 20 metres downstream of the stop line.

- **Speed limit sign (R4-1B) or variable speed limit sign.**
  These signs are located 20m prior to the ramp nose to indicate the speed limit on the carriageway being entered.

- **T2 / Truck lane signs (special sign) to designate the use of the left lane if a priority access lane is provided. The use and positioning of these signs is consistent with Rule 329 of Road Safety Road Rules 2009. The signs are supplemented with a ‘Left Lane’ or ‘Signals do not apply’ sign as appropriate.**

Other signs which may be required in association with a freeway entry ramp, e.g. Merging Traffic warning sign, Emergency Stopping Lane sign etc. shall be provided in accordance with the Traffic Engineering Manual Vol. 2, Chapter 12: Freeway Signs and Markings.

6.4.14. Pavement Markings

The pavement markings and RRPMs associated with the ramp signal designs as shown on the Standard Drawings are provided according to the Traffic Engineering Manual Vol. 2 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 edgeline 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
- The merging from the entry ramp into the main carriageway of the freeway is a lane changing movement, i.e., provide a continuity line
- The stop line is located 10 metres upstream of the traffic signal pedestal.
6.4.15. CCTV Cameras

The provision of a CCTV camera with pan, tilt, zoom capability is included in the ramp signal design to ensure appropriate operator observation during fine tuning of algorithm parameters and operation as well as monitoring queues, driver behaviour and identification of operational problems. Desirable visibility of traffic includes:

- Along the full length of the ramp
- The arterial road approaches, i.e., the left and right turn lanes in case of queue overflow, and
- At the freeway merge.

A camera at the interchange near the ramp entrance generally provides the best coverage of these areas for ramp metering. Alternatively, a camera may be included in the design for installation on the JUMA, JUP 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 arterial road approaches.

6.4.16. 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 where wireless communications are provided to the sign.

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.

6.4.17. Lighting

Generally, street lighting is not specifically required as part of the installation of freeway ramp signals. The need for lighting of the entry ramp may need to be considered in accordance with VicRoads freeway lighting policy and guidelines.
Chapter 7
Operation of Ramp Signals
A general level of information is provided in this chapter relating to the operation of freeway ramp signals and the HERO suite of control algorithms. Further detailed information is in the Freeway Ramp Signals: System Operations Handbook (Internal VicRoads document).

7.1. Legal Basis for Ramp Signals
Freeway ramp signals are traffic lights as defined in Road Safety Road Rules 2009. Rule No. 56 defines a driver’s responsibilities when approaching, or at, a red or yellow traffic light. Other rules define responsibilities relating to the stop line and other regulatory signs and pavement markings associated with freeway ramp signals.

A traffic signal is a Major Traffic Control Device as defined in Road Safety (Traffic Management) Regulations 2009. VicRoads must give approval to erect, establish, display, maintain or remove freeway ramp signals.

7.2. Control Algorithms used by VicRoads
The signal control algorithm used by VicRoads on freeways in Victoria is based on the HERO / ALINEA suite of ramp metering control algorithms. The original ALINEA control philosophy which provides local control at an individual freeway entry ramp was developed by Markos Papageorgiou, Technical University of Crete, Greece (Papageorgiou et al., 1991, 1997). HERO which incorporates an ALINEA module was subsequently developed for coordination of ramp signals at a number of ramps along a length of freeway.

In cooperation with Markos Papageorgiou and Associates, VicRoads has been involved in development and enhancements to the algorithms since an initial trial which demonstrated significant benefits (refer Appendix B).

The algorithms which are field tested with proven results have the following features:

- Dynamic start up and shut down algorithms that ensure the system only operates when required
- Consistency with contemporary traffic theory for optimising freeway flow
- The contemporary control logic is based on feedback from downstream conditions in real-time to dynamically adjust signal cycle times
- Use of occupancy from the downstream freeway bottleneck locations as the optimising measure
- Transparent in operation with fully configurable parameters
- Integrated operation of local ramp control within a coordinated system based on sound operating rationale
- Incorporation of modules for adjustments to entry flow rates based on consideration of ramp queues, and arterial road queues in some cases, as well as ramp delays
- Potential to manage flow at freeway to freeway interchanges by linking upstream ramps on separate freeways
- Ability to manage bottlenecks many kilometres (3 to 4 km) downstream from the nearest ramp
- Potential for consideration of multiple bottlenecks to determine the critical bottleneck.

A summary of the operation of HERO suite of algorithms is outlined in Section 7.6.

Note:
The adoption of a most efficient control algorithm is of paramount importance for a successful ramp metering system. Designing and installing the necessary entry ramp layouts and equipment is necessary and important, but not a sufficient condition for successful operations unless controlled effectively.
7.3. Times of Operation

Freeway ramp signals operating at an isolated ramp or within a coordinated system may be activated in a number of ways.

7.3.1. Dynamic Activation and Deactivation

The dynamic switch-on and switch-off of ramp signals is based on the prevailing freeway traffic conditions. A dynamic system provides traffic responsive operation that activates the metering signals at any time when warranted by freeway traffic flow conditions that could lead to the onset of flow breakdown. The activation and deactivation thresholds are set for each ramp / bottleneck during the manual fine tuning of the system.

The switch-on criteria are based on a combination of speed, occupancy and/or volume. Different criteria are used for starting up and switching off the signals. The switching on criteria are usually set at a relatively low threshold to be sure that the signals start up before the freeway flow collapses. The criteria need to be comprehensive to avoid the signals switching on at an inappropriate time, e.g., high occupancy and low speeds may occur at night due to a slow moving maintenance vehicle.

Usually, stronger criteria are used for switching off the signals to ensure the signals will not start up again soon after the deactivation.

7.3.2. Time of Day Activation

Time of day activation may be used according to critical periods, generally morning and evening weekday peak periods. Scheduled start-up and close-down times are chosen following an analysis of freeway and entry ramp flows during the peak periods and their respective shoulder periods. Typical times of operation would be 6:00am to 10:00am for the AM peak period and between 3:00pm and 7:00pm for the PM peak period. Other times may also be scheduled to cover known occasions outside weekday peak periods where data shows that the freeway service is at risk, e.g., Saturday shopping periods or special events.

Time of day settings may also control the times within which dynamic activation and deactivation may occur. Under this operation the signals may or may not switch on, depending on whether the criteria are met. This form of control for activation is advisable during the initial operation of a new coordinated system and when testing criteria for full dynamic activation.

7.3.3. During Incidents and Events

During periods of light traffic flow on the freeway (when the metering signals would normally be off), there may be advantages in using the signals to manage the headway of entering traffic or to manage the freeway flow. This may be necessary at times of a lane closure or traffic flow breakdown due to planned or unplanned incidents, e.g., roadworks, crashes etc., to assist in traffic management and/or to facilitate service recovery (refer Section 3.7).

7.3.4. Manual Operation

Manual operation or over-ride by an operator is available as required, eg, to be activated to clear queues for access in an emergency.

7.4. Switching on /off Signs and Signals

7.4.1. Start-up Sequence

The sequence for switching on the ramp signals and associated ramp control and warning signs is shown in Figure 7.1 and described below. Prior to start up the signals and RC1 and RC2 signs have no display.

1. Switch Sign RC1 and Sign RC2 to ‘RAMP SIGNALS ON’ and activate the signals to ‘flashing yellow’ for 10 seconds. Activate the variable speed limit (if applicable).

2. Switch on the alternating messages on Sign RC2, if provided, and switch traffic signals to ‘solid yellow’ for 4 seconds.

3. Switch traffic signals to ‘solid red’ for 6 seconds.

4. Commence the metering cycle with the initial green and continue the metering.
### Start-Up Sequence

<table>
<thead>
<tr>
<th>Time</th>
<th>Sign RC1 Variable Ramp Control Sign</th>
<th>Sign RC2 Variable Signals Warning Sign (with Static Sign)</th>
<th>Signals Standard 3-aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to ‘Start Up’ Signs and Signals are off</td>
<td>![Image of Variable Ramp Control Sign]</td>
<td>![Image of Variable Signals Warning Sign]</td>
<td>![Image of Standard 3-aspect signal]</td>
</tr>
<tr>
<td>‘Start up’ Period (10 seconds) Activate the variable speed limit (if applicable)</td>
<td>![Image of Variable Ramp Control Sign]</td>
<td>![Image of Variable Signals Warning Sign]</td>
<td>![Image of Flashing Yellow signal]</td>
</tr>
<tr>
<td>‘Start up’ Period (next 4 seconds)</td>
<td>![Image of Variable Ramp Control Sign]</td>
<td>![Image of Variable Signals Warning Sign]</td>
<td>![Image of Alternating messages] Solid Yellow (4 sec)</td>
</tr>
<tr>
<td>‘Start up’ Period (next 6 seconds)</td>
<td>![Image of Variable Ramp Control Sign]</td>
<td>![Image of Variable Signals Warning Sign]</td>
<td>![Image of Alternating messages] Solid Red (6 sec)</td>
</tr>
</tbody>
</table>

*Figure 7.1: Start-up Control Sequence*
7.4.2. Close-down Sequence

The sequence for switching off the signals is shown in Figure 7.2 and described below.

1. Activate traffic signals to ‘flashing yellow’ and switch Sign RC2, if provided, to ‘Ramp Signals ON’ only (no alternating message) for 10 seconds.

2. Switch off Sign RC1, Sign RC2, the ‘flashing yellow’ of the signals and the variable speed limit (if applicable).

**Figure 7.2: Close-down Control Sequence**
7.5. Operating Sequence and Cycle Times

7.5.1. Signal Timings

Ramp metering operation has a variable cycle time generally in the range 4.0 to 20 seconds according to the determined metering rate. The sequence times based on one vehicle per green per lane are:

- Red: Variable – generally within the range 2.0 to 18 seconds
- Green: 1.3 seconds
- Yellow: 0.7 seconds

Notes:

1. When no vehicles are waiting at the stop line 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.

2. The operation of 2 or 3 vehicles per green per lane has not been trialled successfully in Australia, although used internationally (refer Note in Section 6.3.3). Generally, it is preferable to release a single vehicle per green per lane, even if shorter cycle times need to be adopted.

The entry ramp flows that result from a range of cycle times with varying lane arrangements at the stop line are shown in Table 7 1. In practice, within a dynamic system the cycle time is based on the ability of the freeway to accommodate inflow traffic. The signals apply to all lanes at the stop line.

Time of day signal cycles are used as a ‘fall back’ mode when a dynamic system experiences a fault and fail safe mode is activated.

7.5.2. Minimum Cycle Time

The general minimum cycle time that provides a high entry ramp flow is 5 seconds for a ramp leading to a freeway merge. A general minimum cycle time of 4 seconds could be considered when ramp traffic enters the freeway via an added lane(s) – shaded yellow in Table 7 1. The minimum cycle time would generally operate under light mainline conditions, e.g., during the fringe of the peak periods or where the upstream mainline freeway flow is interrupted due to an unplanned incident. However, the low values are not appropriate in design as an average value over the design hour (refer Section 6.3.3).

Cycle times lower than the minimum indicated are not generally recommended as this could approach a situation where the discharge of vehicles is almost continuous and the metering is relatively ineffective in managing headway. However, lower cycle times may be appropriate subject to trial and assessment of driver behaviour.

7.5.3. Maximum Cycle Time

The general maximum cycle time that provides a low entry ramp flow is 16 seconds and would be implemented when freeway mainline flow is close to or above critical values of occupancy.

Higher cycle times, shaded pink in Table 7 1, may be implemented subject to adopted operational management strategies and driver acceptance, in situations of very heavy freeway congestion, during an incident or when the freeway is recovering from an incident (refer Sections 3.7 and 7.7).
<table>
<thead>
<tr>
<th>Cycle Time (sec)</th>
<th>Cycles per hour (No.)</th>
<th>Equivalent Ramp Flow per hour (veh/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No. of lanes at Stop Line</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>4.0</td>
<td>900.0</td>
<td>900</td>
</tr>
<tr>
<td>4.5</td>
<td>800.0</td>
<td>800</td>
</tr>
<tr>
<td>5.0</td>
<td>720.0</td>
<td>720</td>
</tr>
<tr>
<td>5.5</td>
<td>654.5</td>
<td>655</td>
</tr>
<tr>
<td>6.0</td>
<td>600.0</td>
<td>600</td>
</tr>
<tr>
<td>6.5</td>
<td>553.8</td>
<td>554</td>
</tr>
<tr>
<td>7.0</td>
<td>514.3</td>
<td>514</td>
</tr>
<tr>
<td>7.5</td>
<td>480.0</td>
<td>480</td>
</tr>
<tr>
<td>8.0</td>
<td>450.0</td>
<td>450</td>
</tr>
<tr>
<td>8.5</td>
<td>423.5</td>
<td>424</td>
</tr>
<tr>
<td>9.0</td>
<td>400.0</td>
<td>400</td>
</tr>
<tr>
<td>9.5</td>
<td>378.9</td>
<td>379</td>
</tr>
<tr>
<td>10.0</td>
<td>360.0</td>
<td>360</td>
</tr>
<tr>
<td>10.5</td>
<td>342.9</td>
<td>343</td>
</tr>
<tr>
<td>11.0</td>
<td>327.3</td>
<td>327</td>
</tr>
<tr>
<td>11.5</td>
<td>313.0</td>
<td>313</td>
</tr>
<tr>
<td>12.0</td>
<td>300.0</td>
<td>300</td>
</tr>
<tr>
<td>12.5</td>
<td>288.0</td>
<td>288</td>
</tr>
<tr>
<td>13.0</td>
<td>276.9</td>
<td>277</td>
</tr>
<tr>
<td>13.5</td>
<td>266.7</td>
<td>267</td>
</tr>
<tr>
<td>14.0</td>
<td>257.1</td>
<td>257</td>
</tr>
<tr>
<td>14.5</td>
<td>248.3</td>
<td>248</td>
</tr>
<tr>
<td>15.0</td>
<td>240.0</td>
<td>240</td>
</tr>
<tr>
<td>15.5</td>
<td>232.3</td>
<td>232</td>
</tr>
<tr>
<td>16.0</td>
<td>225.0</td>
<td>225</td>
</tr>
<tr>
<td>16.5</td>
<td>218.2</td>
<td>218</td>
</tr>
<tr>
<td>17.0</td>
<td>211.8</td>
<td>212</td>
</tr>
<tr>
<td>17.5</td>
<td>205.7</td>
<td>206</td>
</tr>
<tr>
<td>18.0</td>
<td>200.0</td>
<td>200</td>
</tr>
<tr>
<td>18.5</td>
<td>194.6</td>
<td>195</td>
</tr>
<tr>
<td>19.0</td>
<td>189.5</td>
<td>189</td>
</tr>
<tr>
<td>19.5</td>
<td>184.6</td>
<td>185</td>
</tr>
<tr>
<td>20.0</td>
<td>180.0</td>
<td>180</td>
</tr>
</tbody>
</table>

Table 7.1: Equivalent Hourly Ramp Flows relative to Cycle Time and Lanes at the Stop Line

**Note:**

Providing separate alternating green signals for each lane to separate the departure of vehicles from the stop line is not endorsed for use at this stage. Although this practice has been used in some instances overseas, evidence is lacking on what is to be gained. Observations of current operation with the simultaneous release of vehicles from the stop line indicates that motorists are able to adjust their position relative to other vehicles leaving the stop line and that separation and merging when entering the mainline is also satisfactory.
7.6. HERO Ramp Metering Operation

7.6.1. Overview
The HERO suite of algorithms used for dynamic coordinated ramp metering control on freeways in Victoria is based on control philosophy developed by Markos Papageorgiou’s group, Technical University of Crete, Greece. The ramp metering operation has two parts:

- ALINEA algorithm and other related kernel algorithms to provide local control at an individual freeway entry ramp, and
- HERO to provide coordination between entry ramps along a length of freeway.

The algorithms use real-time measurements to dynamically adjust signal cycle times based on feedback from downstream freeway bottleneck locations as well as data from ramps. The algorithms are consistent with contemporary traffic theory for optimising freeway flow and are transparent in operation with fully configurable parameters to suit the geometry and traffic conditions on the freeway and at each ramp.

The mainline bottleneck is typically at the merge of an entry ramp but may also be a result of other downstream geometric factors such as merging at a lane drop, a steep upgrade, a tight radius curve, reduced lane widths or areas with high weaving or lane changing movements, e.g., just upstream of a lane gain or high flow exit ramp.

Occupancy at the mainline bottleneck is the principal measure used to manage traffic flow on the freeway to optimise throughput and prevent flow breakdown, i.e., congested flow. As average lane occupancy on the mainline approaches a value that may be unstable, ramp entry flow is controlled to regulate the mainline occupancy at an optimum value. Accurate and reliable data from detectors is essential.

7.6.2. HERO Operation
The HERO suite of algorithms manage the ramp traffic flow entering the freeway by monitoring and controlling the freeway flow at the ramp merge or other downstream bottleneck. Ramp exit flow calculations are based on modules providing outputs for local and coordinated operation as shown in Figure 7.3.

---

**Figure 7.3: HERO Coordinated Ramp Control**

### Local Ramp Control
- Data processing
- Fail safe checks
- Activation / deactivation
- ALINEA operation
- Critical occupancy estimation
- Queue estimation
- Queue control
- Queue override
- Ramp delay (waiting time)

### Ramp Coordination
- Hero operation
- Minimum queue control

### Ramp Entry Flow Implementation
- Assessment of module outputs
- Consideration of ramp waiting times
- Cycle time implementation
The algorithm uses flow, speed and occupancy data in various modules that include:

**7.6.2.1. Activation / Deactivation**
This module switches the freeway ramp signals on according to preset traffic flow, occupancy and speed thresholds at the mainline bottleneck location downstream of the ramp. The ramp signals are switched off according to preset occupancy and speed thresholds. Activation and deactivation is independently controlled at each ramp within a coordinated system. The thresholds are set with the intention of turning on the signal control before the onset of flow breakdown and turning the metering signals off when traffic flow conditions indicate that flow breakdown is unlikely.

**7.6.2.2. ALINEA Core Module**
This module calculates the desired ramp flow at each entry ramp for local maximisation of mainstream throughput according to the ALINEA feedback control algorithm. The calculation uses the average mainstream occupancy measurement downstream of the merge (or other downstream bottleneck) relative to a targeted critical occupancy value. The targeted critical occupancy at the mainline bottleneck is either set for each ramp by the user or it is dynamically calculated by the critical occupancy estimation module.

**7.6.2.3. Critical Occupancy Estimation Module**
This module calculates the critical occupancy at the downstream bottleneck. Where this module is activated the calculated value is used in the ALINEA core module as the targeted critical occupancy value. The adjustment of the critical occupancy value considers the flow / occupancy relationship that optimises capacity and prevents flow breakdown (refer Figure 3.5), as well as the path of flow recovery if flow breakdown has occurred (refer Section 2.3.3).

**7.6.2.4. Queue Estimation Module**
For each controlled entry ramp, this module uses the flow measurements of the ramp entrance detectors and the ramp exit as well as the average occupancy of the detectors in the middle of the ramp to calculate an estimate of the queue length on the ramp.

**7.6.2.5. Queue Control Module**
For each controlled ramp, this module uses the estimate of the queue length of the ramp (calculated by the queue estimation module) and the average flow measurement of the detectors located at the ramp entrance (ramp demand) in order to calculate a desired ramp exit flow to minimise the risk of queue overspill. This flow value needs to be determined so that traffic can still be absorbed into the mainline and to minimise the potential for causing flow breakdown on the mainline.

**7.6.2.6. Queue Override Module**
This module enables the ramp entrance/arterial road interface to be managed. In the event that the ramp queue will exceed the available ramp storage, a pre-specified ramp exit flow is activated to increase the metering rate. This ramp exit flow value needs to be determined to avoid an excessive inflow of traffic to the mainline that may trigger flow breakdown. While optimising the freeway throughput has benefits to the road network as a whole, consideration may also need to be given to the implications of ramp queues extending onto the arterial road.

**7.6.2.7. HERO Coordinated Operation**
The HERO module coordinates local ramp metering actions in order to balance queues and provide equity between ramps in a coordinated system.

HERO is activated when a ramp operating under local control experiences queues that meet pre-set thresholds, based on the available ramp storage. In this event the ramp becomes a ‘master’ and engages the first upstream ramp as a ‘slave.’ The algorithm then balances queues between the ramps. The engagement of further upstream ramps as slaves continues within a coordinated group, as required.

While the system is operating in a coordinated manner under HERO, control using ALINEA and related algorithms at each individual ramp continues according to local needs at the ramp merge bottleneck.
7.6.2.8. Minimum Queue Control Module

When coordinated ramp metering is in operation, i.e., HERO has been activated, this module uses the estimate of the ramp queue length and the flow at the ramp entrance to calculate a desired metered flow rate so that the minimum queue calculated by HERO is implemented. This calculation aims to make best use of available storage on coordinated ramps and to balance queues between the ramps.

7.6.2.9. Final Ramp Flow Specification Module

This module calculates the final ramp exit flow to be applied to a ramp at the next control period. In the case of local ramp metering the final ramp flow decision is based on exit flow values calculated by ALINEA as well as consideration of the various flow values to address ramp queues. In the case of coordinated ramp metering the final ramp flow is based on ALINEA as well as individual ramp queues and the balancing of queues between ramps. The final ramp flow calculation also considers the current waiting time on the ramp relative to a pre-specified maximum wait time value. The final flow rate may also be adjusted to be within pre-specified minimum and maximum flow rates.

7.6.2.10. Implementation Module

The implementation module calculates the cycle time (the sum of green, yellow and red) that corresponds to the final ramp flow, considering the number of lanes at the stop line. The implemented cycle time is changed for each control period within pre-specified increments for cycle time increases and decreases.

7.6.3. Enhancements to Provide Advanced Bottleneck Control (ABC)

At the time of writing this handbook a number of additional enhancements are under development to provide advanced bottleneck control (ABC). These include:

- Managing freeway flow by considering data at multiple downstream bottlenecks simultaneously. For example, this will enable superior freeway control by considering flow at a steep grade, tight curve, weaving area or uncontrolled freeway to freeway merge as well as the entry ramp merge. This will also enable automated substitution of data in the event of a mainline data station fault.

- Managing entry flows from dual branch entry ramps. This will optimise and balance the ramp flows from each ramp based on queues and waiting time yet still manage the total entry flow based on a single critical downstream bottleneck. This form of operation could also be applied to providing a higher metering rate for a metered priority access lane.

Note: VicRoads has entered into a licence agreement with the developers of ALINEA and HERO, Markos Papageorgiou and Associates, for the use of the algorithms. Since initial trials of the algorithms, VicRoads has worked closely with the developers in regard to further development and improvement.

7.7. Ramp Signals Response to Emerging Congestion

7.7.1. General Principles

The management of freeway flow with ramp signals is intended to maintain free flowing conditions and to prevent flow breakdown. However, there are times when freeway delays become excessive due to congestion caused by an event, e.g., an incident or roadworks, or a situation where the freeway ramp signals are unable to prevent the congestion occurring. The activation of other managed freeway tools, such as a lane use management system closing a lane or a variable speed limit system activating lower than normal speed limits, creates travel conditions that require targeted strategies for managing the freeway and operating the ramp metering signals.

For example, during increasing freeway flow the ramp signal algorithms manage the traffic to prevent congestion. The usual operation of the algorithms would reduce flows into the freeway and increase ramp queues, including engagement of upstream ramps and balancing of queues.
Subsequent queue management would generally increase the metering rate into the freeway to prevent the queue overflowing onto the arterial road. With increasing congestion, increasing the metering rate would generally worsen freeway conditions, as vehicles enter the freeway at a rate that cannot be accommodated. Modifying the operation of the ramp signals improves the effectiveness of traffic management during congestion and facilitates recovery from congestion to free flowing conditions. Section 3.7 provides further background relating to managing congestion and incidents.

Automated strategies and actions\(^4\) to modify the ramp metering operation as well as provide special traveller information signing to assist in diversion of traffic away from the freeway, is required. This includes freeway management system enhancements to:

- Override the calculated output from the ramp signal algorithms. This works to restrict over supply of entering traffic when the freeway travel time on the downstream travel time segment reaches preset thresholds
- Provide real time information signs (RC3) that will give advice relating to the freeway condition and travel time. These signs enable motorists to make an informed decision regarding route choice. Examples of sign messages are in Figure 7.4 and further information is provided in traveller information guidelines
- Adjust inputs to the control algorithms relating to abnormal circumstances during an event, e.g., a lane closure, and provide appropriate traffic control actions.

\(^4\) Under development at the time of writing. Principles are outlined in Section 7.7.2 and Appendix D.

**Figure 7.4: Examples of RC3 Freeway Condition and Congestion Messages**

7.7.2. Ramp Signals Control

When a freeway becomes congested the HERO suite of algorithms initially minimises entry ramp flows into the freeway. However, as the entry ramp queues develop on one or more ramps, the long vehicle queues activate the Queue Control and Queue Override Modules which take control of the entry ramp flows. The higher flows entering the freeway can cause mainline flow breakdown and/or increase congestion along the freeway.

To manage the freeway during heavy congestion, additional strategies are employed outside of the HERO operation in which the ramp flows are restricted to lower values. This intervention will reduce the extent of worsening congestion and facilitate faster recovery from congestion. This results in the achievement of higher overall productivity from the freeway asset. Different strategies are progressively applied depending on the level of congestion. The modified operation will also cause longer ramp queues which may affect arterial roads for a limited period of time.

The travel time algorithm considers a number of downstream detector stations that provide a valuable indication of congestion over a significant length of freeway. Operation to reduce the metering rate and advise motorists of long delays on the freeway is based on the relationship of the estimated travel time to the nominal travel time for the downstream section of freeway.

Further detail relating to modifying the metering rate is in Appendix D.
7.8. Ramp Signals Integration with other Managed Freeway Operations

7.8.1. Ramp Signals Response to a Lane Closure
When an incident results in a lane closure, this induces a significant bottleneck that would generally have a major adverse impact on traffic flow. Lane closures of this nature are random and variable in relation to nominated (pre-set) bottlenecks within the set up of the freeway ramp signals. A lane closure activated by the lane use management system (LUMS) or at other locations not controlled by LUMS, restricts the number of lanes for the traffic flow.

When a lane closure occurs, the freeway management system provides the number of lanes available at a location relative to the number of lanes normally available. The lane closure situation is addressed within the control algorithm to determine the critical bottleneck from a number of potential downstream bottlenecks. The multiple bottleneck capability within the algorithm will automatically evaluate the critical flow conditions and regulate the ramp flow accordingly.

7.8.2. Ramp Signals Response to Changing Speed Limits
Freeway ramp signals switch on and off automatically within thresholds based on freeway flow, travel speed and occupancy. When the freeway speed limit is reduced by a variable speed limit system (VSL), the ramp signals could activate unnecessarily under fixed value activating parameters.

In a managed freeway, a variable speed limit lower than the default speed may be activated in concert with LUMS or for other reasons, e.g., high winds on a bridge. The lower travel speed of traffic affects pre-set values for activation and deactivation of the freeway ramp signals. To ensure that ramp metering is not falsely triggered by a speed limit lower than the default limit, the freeway management system provides the current speed limit value for calculations associated with the ramp signals.

7.8.3. Ramp Signals Response to a Freeway Closure
When an event requires a ramp closure, either of the ramp or the downstream section of freeway, the following operation will occur:

- The Real Time Information Signs (RC3) will display the appropriate freeway closed message as outlined in the handbook for traveller information and incident management, and
- The RC1 sign will display a FREEWAY CLOSED message alternating with a symbolic No Right Turn / No Left Turn / No Entry sign or Special message as appropriate, and
- The freeway ramp signals will switch off by initiating the usual close-down sequence. Switching off the signals enables vehicles already on the ramp to clear so that an emergency vehicle can enter, if necessary. Switching the signals off also avoids vehicles being trapped on the ramp. Further entry of vehicles is restricted by the RC1 and RC3 signs.

The ramp closure operation may be activated manually or automatically as part of an incident response. Reopening of the ramp may also be initiated manually or automatically when there is no longer a need for the closure. When the freeway ramp is reopened to traffic the system would return to default ramp operation, i.e., subject to traffic needs at the time, the ramp signals start up operation may or may not occur.

7.8.4. Emergency Vehicle Access when Ramp Signals are Operating
The queues at ramp signals may present problems for emergency vehicle access during an incident where the ramp is not closed as part of the incident response. Where an emergency vehicle requires access at a particular ramp, the emergency service will need to contact the Traffic Management Centre (TMC).

To provide uninterrupted access for the emergency vehicle the TMC operator will manually turn off the ramp signals to clear the ramp queue. After entry of the emergency vehicle the operator would then re-enable the ramp signals to continue the metering.
Chapter 8
Arterial Road Access Management
8.1. General Principles

Section 3.3 outlines the principles associated with the integration of managed freeways with the arterial road network to achieve an effective freeway / arterial 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. This implies that entry and exit ramp flows need to be given priority over the arterial road.

8.2. Managing Entry Ramp Queue Overflows

8.2.1. Potential Ramp Problems

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

Ideally, ramps should be designed to accommodate queues as described in Section 6.3.4. 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 extend ramp storage, the traffic queues may extend onto the arterial road network. In other cases it may be more economical to provide for storage on the arterial road rather than extend the freeway ramp. In this situation the additional storage should be provided to avoid interference with arterial road flows.

During real time operation, the queue override module in the HERO suite of algorithms enables the ramp entrance / arterial road interface to be managed as outlined in Section 7.6.2. In the event that the ramp queue will exceed the available ramp storage, a pre-specified ramp exit flow can be activated to increase the metering rate. This ramp exit flow value needs to be determined to avoid an excessive inflow of traffic to the mainline that may trigger flow breakdown. Although the system has some capability to increase ramp flow it may not prevent queuing onto the arterial road.

During design where queues are expected to extend onto the arterial road on a regular basis, the design may need to provide for detection of queues on the arterial road and/or include provisions to accommodate queue overflows as outlined in Section 8.2.2.

The evaluation of ramp queue overflow may also need to consider the capabilities of the road network to accommodate trip diversions (refer to Section 3.3). Where significant volumes cannot be managed on an existing or proposed entry ramp / arterial road approach, further consideration may need to be given to providing a freeway or entry ramp design with greater storage or higher capacity.

8.2.2. Treatment Options

Some drivers will adapt to changing freeway accessibility and modify their travel patterns (route 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 6.4.12.3 and Section 7.7 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 freeway condition. Where ramp overflows and long delays are expected motorists may choose to take an alternative route.
To manage ramp queue overflow traffic, the following treatment options may need to be considered.

1. Interfacing between the freeway ramp signal system and the SCATS system. Control actions can then be initiated within the SCATS intersection controller.

2. Treatments to manage the right turn traffic entering the ramp include:
   a) Modify the right turn signal phase times to restrict traffic entry.
   b) Skip the right turn phase during affected times.
   c) 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:
   a) Providing or extending left turn lane storage to ensure queuing is clear of through traffic lanes;
   b) Ensuring appropriate equity between the left and right turning demands:
      - Provision of signals on a left turn slip lane. This treatment is more likely to be needed with a Type 1 left turn entry (refer Section 6.4.10.3) or if there is an imbalance between the left and right turn flows with a high left turn volume.
      - Restricting left turn overlap times.
      - Installing a red left turn arrow.

The implementation of these measures has the potential to worsen queues on the arterial road and should only be considered where a demonstrated need exists.

4. Modify the phase times at other arterial road intersections to provide for traffic diversions.

8.3. Managing Exit Ramp Queuing

8.3.1. Potential Mainline Problems

Traffic flow on the freeway mainline is affected when traffic queues on an exit ramp extend back to block the left lane of the freeway or cause traffic to slow down prior to exiting as shown in Figure 8.1. This may cause flow breakdown on the mainline under certain conditions. It is also a significant safety concern for exiting traffic and for through traffic on the mainline. As indicated in Section 3.8, ramp metering of upstream entry ramps has limited effectiveness in addressing this problem.

![Figure 8.1: Exit Ramp Queue Affecting Freeway Flow](image-url)
The problem of exiting vehicles causing flow problems on the freeway carriageway may be a result of:

- Inadequate intersection capacity at the arterial 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 arterial road approaches to the intersection which limit the time that can be allocated to the exit ramp, e.g., insufficient through or turning lanes
  - Stop or Give Way signs at the ramp exit
  - Unbalanced flows at a roundabout interchange.
- Inappropriate signal phasing and/or timings. The SCATS stop line detectors are able to determine if queues not 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 arterial road downstream of the interchange that may restrict traffic departing the intersection
- Adequate intersection capacity but inadequate ramp capacity to handle high exiting flows, e.g.,
  - A short ramp with insufficient length back to the mainline to accommodate queues
  - Insufficient width to enable the ramp to accommodate the exit flow, e.g., a single lane exit ramp where flow has increased to the extent that two lanes are required.

The safety of traffic related to exiting the freeway and the impact on capacity are important freeway 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 of giving freeway operation priority over the arterial 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. Therefore, getting traffic off the freeway should be seen as the highest priority with other movements being given lesser priority.

8.3.2. 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 arterial road traffic signal phase settings to facilitate a general increase in exit ramp traffic discharge.
2. Modify the arterial road traffic signal phasing to provide a specific exit ramp phase extension when the ramp queue is long. The queue length would be determined by the provision of a detector near the exit ramp nose to detect a queue extending beyond the ramp length. This data could be provided by:
   - Data station detectors near the exit nose. This data cannot be directly input into SCATS. However, the SCATS – STREAMS interface will be able to provide input when it is available. Existing detectors may be suitable or additional detectors provided if existing data station detectors are not suitably located.
   - Provide SCATS queue detection loops near the exit ramp nose to facilitate direct adjustment of the signal timings;
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 arterial 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 arterial road intersection, provide roundabout metering signals to facilitate exit ramp egress.
5. Considering downstream improvements on the arterial 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 exiting lanes from the freeway mainline and the ramp width.
8. Allow 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.

8.3.3. Exit Ramps Design Storage

The provision of adequate exit ramp storage for new or upgraded freeway exit ramps is desirable to avoid the problems of exit ramp queues extending back and interfering with mainline freeway traffic flow. Desirable design standards include full length right turn and left turn lanes to accommodate 95th percentile queues.
Appendices
APPENDIX A: Freeway Ramp Signals - Information Bulletin
This Appendix provides an example of a Freeway Ramp Signals Information Bulletin.

Freeway Ramp Signals
An intelligent system to maximise freeway performance

INFORMATION BULLETIN
Introduction
Traffic congestion is common on Melbourne’s freeways during peak times and often occurs around freeway entrances where a surge of traffic enters the freeway. This can cause the traffic on the freeway to slow down and sometimes results in stop-start conditions, which means the freeway operates well below its maximum capacity.

Congestion and stop-start conditions on freeways delay traffic, cause frustration for motorists, extend journey times and increase the risk of crashes. Journey times are often three to four times higher during the peak period compared to the off-peak period.

In 2002, VicRoads introduced a new system to make the freeway travel easier, safer and more reliable. This system has been successfully implemented at more than 10 sites on Melbourne’s freeway network. This system uses traffic lights to allow traffic entering the freeway to join safely and easily with the freeway traffic. The current system has been operated in an isolated manner at each site and has improved the freeway performance. However, ongoing monitoring has indicated that the freeway is still operating below its maximum capacity.

To meet current and future needs of the road network, VicRoads is implementing an improved and coordinated control system. The new Freeway Ramp Signals are designed to improve the quality of service to all traffic entering the freeway. A state-of-the-art technology from Europe is incorporated into the new system.

What are Freeway Ramp Signals?
The new system will be dynamic and responsive to traffic creating the ability to manage traffic along a freeway corridor rather than at individual locations. This enables a number of consecutive ramps to be regulated to balance traffic along the route so that the freeway operates to provide optimum performance. The coordinated system will manage and control entering traffic to minimise stop-start conditions which are brought about by a high volume of traffic or incidents. The system would also enable faster recovery from a freeway incident.

As part of the Monash-Citylink-Westgate Upgrade Project, Freeway Ramp Signals will be initially installed between Narre Warren and Werribee. The system will manage access to the freeway to enable:
- easier merge;
- safer flow;
- smoother flow (less variation in speed);
- minimal delays;
- reliable travel time (travel certainty); and
- higher efficiency (up to 10 percent increase in traffic throughput).

Figure 1 Before the implementation
- Congested - stop/start condition
- Long delays
- Variable travel time
- Low efficiency - (poor flow)

Every vehicle entering the freeway contributes to the freeway congestion
What do I see on the road?

Electronic message signs at the freeway entrance let you know if the Freeway Ramp Signals are operating.

Freeway Ramp Signals are located part way along the freeway entrance. They have the same meaning as other traffic signals. However, the traffic cycle will be much shorter than normal - typically the waiting time at a red light varies between 5 and 15 seconds in response to freeway conditions. When traffic flow along the freeway route is high, you may need to wait longer before entering the freeway.

A stop line is painted on the road next to the traffic lights to show you where to stop.

Freeway ramp signals

Signs on the traffic light poles will let you know that only one vehicle in each lane may enter the freeway on a green signal.

At some locations, a special purpose lane is provided for trucks or vehicles with more than one person. This will allow these vehicles to access the freeway without delay by the signals.

When the freeway is heavily congested, e.g. due to an incident, message signs are switched on to warn motorists on the main roads that long delays can be expected on the freeway and entry ramp. This enables motorists to choose alternative routes.

How do the Freeway Ramp Signals work?

Freeway Ramp Signals will generally operate during peak hours and any time of the day when freeway conditions are heavy.

The Freeway Ramp Signals relieve congestion in a similar way to traffic signals on main roads by regulating traffic demand in an orderly manner.

They will start working when roadway sensors indicate that traffic on the freeway are heavy. At times it may seem Freeway Ramp Signals are in operation when the freeway is uncongested. This may be due to congestion at other locations along the freeway. Freeway Ramp Signals will continue to operate until the overall freeway traffic flow improves.

Freeway Ramp Signals also aim to improve traffic flow by balancing the queues on adjacent ramps to create fairness for all drivers.

Figure 2 After the implementation

- Smoother and safer flow
- Easier merge
- Minimal delays
- Reliable travel time
- Higher efficiency

Freeway free-flow conditions maintained
What do I do when:

the lights are switched off?
Merge with the freeway traffic as you would normally do.

the lights are flashing yellow?
This occurs when the system is starting up or shutting down. You should merge with the freeway traffic as you would normally do.

the lights are red?
Stop at the stop line and wait for a green light.

the lights are green?
If you are the first vehicle in the queue, you can drive past the traffic lights and merge with the other vehicle leaving the signals. You can then merge with the freeway traffic as you would normally do.

Other vehicles in the queue must wait their turn, as only one vehicle per lane is allowed to join the freeway traffic on a green light.

What are the benefits?
Freeway Ramp Signals are expected to deliver the following benefits:
- easier and safer merging from freeway entrances;
- reduced congestion and improved traffic flow on the freeway;
- smoother travel and more reliable journey times;
- improved safety for motorists joining the freeway traffic and for those already travelling on the freeway;
- reduced vehicle emissions; and
- improved priority for trucks and vehicles with more than one person at some locations.

For further information:
Contact Monash-CityLink-West Gate upgrade project team:
Monash-CityLink-West Gate upgrade
PO Box 1644 Melbourne VIC 3001 Tel: 1300 881 137
Email: info@mcwupgrade.com.au Website: www.mcwupgrade.com.au
APPENDIX B: Short History of Ramp Metering

B1: Ramp Metering Internationally

North America

The US Federal Highway Administration Ramp Management and Control Handbook (2006) indicates that the first ramp metering was installed in 1963 on Chicago’s Eisenhower Expressway. Ramp metering was developed as a technique to manage traffic demand following the launch of the Interstate Highway Program to address freeway flow problems associated with congestion and safety.

The initial application of entry ramp metering used a police officer stationed on the entrance ramp to stop traffic and release vehicles one at a time at a rate determined from a pilot detection program. This use of metering followed successful tests of the effectiveness of metering traffic entering New York tunnels and ramp closure studies in Detroit (Piotrowicz. and Robinson, 1995).

The Minnesota Department of Transportation (Mn/DOT) has extensive use of ramp meters to manage freeway access on approximately 210 miles of freeways in the Twin Cities metropolitan area. Mn/DOT first tested ramp meters in 1969 as a method to optimize freeway safety and efficiency in the metro area. Since then, approximately 430 ramp meters have been installed and are used to help merge traffic onto freeways and to manage the flow of traffic through bottlenecks.

While ramp meters have a long history of use by Mn/DOT as a traffic management strategy, some members of the public questioned the effectiveness of the strategy. In 2000 the Minnesota Legislature required Mn/DOT to study the effectiveness of ramp meters in the Twin Cities Region by conducting a shutdown study. The evaluation report by Cambridge Systematics Inc. (2001) indicated the following annual benefits of ramp metering:

- Traffic Volumes and Throughput: After the meters were turned off, there was an average 9% traffic volume reduction on freeways and no significant traffic volume change on parallel arterials included in the study. Also, during peak traffic conditions, freeway mainline throughput declined by an average of 14 percent in the “without meters” condition.

- Travel Time: Without meters, the decline in travel speeds on freeway facilities more than offsets the elimination of ramp delays. This results in annual systemwide savings of 25,121 hours of travel time with meters.

- Travel Time Reliability: Without ramp metering, freeway travel time is almost twice as unpredictable as with ramp metering. The ramp metering system produces an annual reduction of 2.6 million hours of unexpected delay.

- Safety: In the absence of metering and after accounting for seasonal variations, peak period crashes on previously metered freeways and ramps increased by 26 percent. Ramp metering results in annual savings of 1,041 crashes or approximately four crashes per day.

- Emissions: Ramp metering results in a net annual savings of 1,160 tons of emissions.

- Fuel Consumption: Ramp metering results in an annual increase of 5.5 million gallons of fuel consumed. This was the only criteria category which was worsened by ramp metering.

- Benefit/Cost Analysis: Ramp metering results in annual savings of approximately $40 million to the Twin Cities travelling public. The benefits of ramp metering outweigh the costs by a significant margin and result in a net benefit of $32 to $37 million per year. The benefit/cost ratio indicates that benefits are approximately five times greater than the cost of entire congestion management system and over 15 times greater than the cost of the ramp metering system alone.

The number of ramp meters operating in North America has now increased to over 2300. This...
is seen as a measure of the benefits and success of ramp metering installations. The following quote from the Federal Highway Administration, Ramp Management and Control brochure (2006) demonstrates the value of ramp metering systems:

"Every evaluation of the system has shown reduced accidents, reduced delay and increased volumes when metering was installed. No other traffic management strategy has shown the consistently high level of benefits in such a wide range of deployments from all parts of the country".

Pete Briglia, Puget Sound Regional Council, Seattle, Washington and Chair of the TRB Freeway Operations Committee.

United Kingdom

In 2005 the UK initiated the installation of ramp meters. There are currently around 90 installations that comprise a series of isolated meters throughout the country with operation based on the ALINEA algorithm.

The EURAMP Project

The EURAMP project was initiated by the European Community to fill a number of methodological, technological and practical gaps in the global aim of advancing the ramp metering control measures in Europe and elsewhere for the sake of traffic flow efficiency and safety. The project has included a number of activities including:

- Methodological developments related to various ramp-metering aspects including ramp queue estimation and control, metering policies, adaptive features as well as enhancement and design of new coordinated strategies
- Field installation and demonstration of developed aspects and strategies in four countries (France, The Netherlands, Germany and Israel)
- Focus on some safety-critical issues such as the development of a risk indicator for motorway traffic flow and the potential, safety-increasing co-operation of ramp metering with future in-vehicle devices and systems
- Preparation of a Handbook of Ramp Metering and creation of an electronic User Group for dissemination, feedback and discussion; operation of a helpdesk providing advice for new installations
- Multiple dissemination (web site, publications, presentations, Workshop, User Group meetings, special sessions at conferences) and exploitation activities.

New Zealand

New Zealand’s first trial of ramp metering was carried out at the Esmonde Road on-ramp on the Northern Motorway, Takapuna, in 1982, as part of the New Zealand’s National Roads Board Research Project DC5. The trial lasted five months, towards the end of which some 20 days of ramp metering took place. Traffic responsive metering varied the cycle time according to the amount of traffic the freeway could accommodate. The layout provided two lanes at the stop line and a ‘buses only’ unmetered priority lane. A report of the trial (Traffic Engineering and Control, November, 1983), indicated that smooth capacity flow conditions could be maintained for long periods (>20 minutes), during which time the motorway exhibited a most unusual behaviour that was called ‘superflow’ with average flows of 2160 veh/lane, with the median or fast lane operating nearer to 2400 veh/lane.

A subsequent New Zealand Easy Merge Ramp Signal (ramp metering) trial then commenced in March 2004 at the Mahunga Drive northbound on-ramp on SH20. The control and operation used the SCATS Ramp Metering System (SRMS). Evaluation of the trial (Brown, T., et al, 2005) concluded that ramp metering has successfully improved the performance of the road network within the vicinity of the ramp metering site with significant increases in throughput and travel speed.
B2: Ramp Metering in Melbourne

First Ramp Metering Initiative in 1971

The first ramp metering in Australia was provided in Melbourne on the South Eastern Freeway (now the M1 - Monash Freeway / SouthernLink) at the Gibdon Street entry ramp.

The ramp metering was initiated in 1971 by Mr Kerras Burke of the Highways Division of the Melbourne and Metropolitan Board of Works (MMBW). The rate of vehicle entry to the freeway was based on data from detectors on the freeway. The traffic was regulated by varying the phase times at traffic signals at the Entry ramp / Gibdon St / Barkly Av intersection.

A paper presented by Kerras Burke at the Fifth Australian Computer Conference in Brisbane in May 1972, is attached to this Appendix.

The metering had limited success due to the high freeway flows. The limited spare capacity resulted in low ramp phase time for allowing additional vehicles to enter from the ramp. The release of short platoons from the controlling signals at the top of the ramp (rather than signals close to the nose with one vehicle per green) was also less than desirable. The metering was eventually deactivated due to driver complaints about short phase times, lack of publicity to inform motorists, non compliance and lack of enforcement.

Other Investigations

In the early 1970s other investigations promoted the value of ramp metering. A report, 'Some Aspects of Freeway Design and Operation' (1971) was written by Robin Underwood, Assistant Chief Road Design Engineer, Country Roads Board. The report was the result of a Churchill Fellowship Study Tour of the United States, Canada, Great Britain and Europe. The report indicated that ‘a fundamental part of most surveillance and control projects is ramp control.’ The report included a summary of operational practice at that time in the countries visited, as well as a range of other matters relating to freeway design and operations.

Ramp Metering Trial in 2002

Despite the initial application of ramp metering in 1971, there was no further ramp metering in Melbourne until 2002. In view of Melbourne’s freeway flow problems leading up to that time, Gary Veith (VicRoads) initiated a study relating to best practice in freeway management.

A September 2000 report, “Managing Traffic Flow on Urban Freeways”, prepared by Andrew O’Brien and Associates (now O’Brien Traffic) lead to an initial trial of metering at the Thompsons Road eastbound entry ramp on the Eastern Freeway where extensive queues on the freeway resulted from flow breakdown caused by merging traffic. The initial stage of the trial modified the right turn phase times to regulate the flow into the ramp from the Thompsons Road / Entry ramp intersection.

Following the success of modifying right turn signal timings, the second stage of the trial included the installation of traffic signals on the ramp to meter the entering traffic into the freeway flow. Andrew O’Brien continued his involvement with investigation and design. Bill Saggers (VicRoads) managed the project as part of VicRoads ‘Easy Merge – Safer Flow’ ramp metering trial.

The ramp meter design provided two lanes at the stop line with one vehicle per green per lane released each cycle. The metering signals were switched on by time of day for the evening peak period. SCATS controllers were used to provide fixed time cycles of 9 seconds at initial switch on and 6 seconds for periods when the ramp queue became significant.

A ‘Before and After’ study indicated the success of the project in preventing traffic flow breakdown to provide more consistent traffic flow and reduce travel times on the freeway. The results of the study indicated:

- Up to 70 per cent increase in speed on the Eastern Freeway at Bulleen Road as a result of avoiding flow breakdown as shown in Figure B-1.
- Over the section of the Eastern Freeway between Bulleen Road and Doncaster Road, free flow speeds improved and up to 60 per cent reduction in travel times, as shown in Figure B-2. For this short section of freeway the installation saved an estimated 20,000 hours of delay annually. The extended distance upstream that had been impacted beforehand has also experienced significant benefit.
After the initial trial, other isolated ramp meters installed on the Monash Freeway also improved the ramp merge, reduced delays on the freeway and reduced flow breakdown. However, these benefits have reduced over time due to increasing traffic demands along the freeway and the limited value of isolated fixed time operation. This experience has confirmed that to control performance at the critical bottlenecks, high volume freeways need to be managed in a dynamic coordinated manner to control all inflows.

Importantly, these initial installations confirmed that:

- Implementation and broader use of this intelligent transport system technology is a cost effective means (typically BCR in excess of 10) of providing a more reliable, safer and less stressful service to road users
- Other more costly infrastructure improvements can be avoided or delayed through increased utilisation (productivity) of the existing high value infrastructure, and
- Melbourne’s motorists demonstrated that they were able to adapt to the ‘radical’ traffic control with a high level of compliance, and also supported the initiative.\(^5\)

\(^5\) Anecdotal information

<table>
<thead>
<tr>
<th>Site</th>
<th>Switch on Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Fwy / Thompsons Rd, OB</td>
<td>28/06/2002</td>
</tr>
<tr>
<td>Monash Fwy / Huntingdale Rd OB</td>
<td>20/11/2002</td>
</tr>
<tr>
<td>Monash Fwy / Warrigal Rd OB</td>
<td>29/04/2003</td>
</tr>
<tr>
<td>Monash Fwy / Warrigal Rd IB</td>
<td>18/08/2003</td>
</tr>
<tr>
<td>Monash Fwy / Blackburn Rd IB</td>
<td>08/07/2004</td>
</tr>
<tr>
<td>West Gate Fwy / Montague St OB</td>
<td>13/09/2004</td>
</tr>
<tr>
<td>Monash Fwy / Ferntree Gully Rd IB</td>
<td>14/02/2005</td>
</tr>
<tr>
<td>Monash Fwy / Blackburn Rd OB</td>
<td>17/10/2005</td>
</tr>
<tr>
<td>Monash Fwy / Forster Rd IB</td>
<td>28/10/2005</td>
</tr>
<tr>
<td>Monash Fwy / Forsters Rd IB</td>
<td>28/10/2005</td>
</tr>
<tr>
<td>Calder Fwy / Keilor Park Dr OB</td>
<td>06/12/2005</td>
</tr>
<tr>
<td>Monash Fwy / Wellington Rd IB</td>
<td>19/12/2005</td>
</tr>
</tbody>
</table>

Developments Leading to Current Practice

In 2004 John Gaffney undertook a 2 month technical tour to the USA, UK and Europe as part of the Kerry Burke Memorial Scholarship. During the trip significant information was obtained relating to contemporary traffic flow theory, freeway flow management and freeway ramp metering.

In November 2005 the VicRoads Guidelines for Managing Freeway Flow with Ramp Metering developed by Maurice Burley and John Gaffney was published following a review of available international literature and current practice. Technical review and input were provided by Bill Saggers and Andrew O’Brien (O’Brien Traffic).

In 2005 and 2006 Darren Patterson (Transurban) as well as John Gaffney and Vincent Vong (VicRoads) carried out reviews of best practice for ramp metering algorithms. VicRoads subsequently approved the ALINEA and HERO algorithms for use in Melbourne.

Dynamic Coordinated Ramp Metering System Pilot 2007/08

In 2007/2008 the implementation of a dynamic coordinated system on Monash Freeway using the ALINEA and HERO algorithms demonstrated significant benefits over the isolated fixed time metering which it replaced. As part of the Monash–CityLink–West Gate Upgrade Project an initial pilot included coordinated operation of ramp signals at six inbound entry ramps between Jacksons Road and Warrigal Road. ‘Before and after’ speed contour plots based on operation in 2007 and 2008 are shown in Figures B-3 and B-4. Comparisons relative to the Austroads National Performance Indicators are shown in figure B-5.

The dynamic coordinated system reduced freeway traffic flow breakdown and provided significant improvements in throughput and travel speed. Markos Papageorgiou and Ioannis Papamichail from the Technical University of Crete provided technical input in regard the ramp metering operation and optimising freeway traffic flow. Transmax Pty Ltd (Queensland) was involved in the software development and the use of the STREAMS platform for the ramp metering trial. The coordinated freeway ramp signals pilot project was a world-first application of the coordinated HERO traffic management technology.
The Coordinated Freeway Ramp Signals Pilot was awarded excellence awards in the Engineering Innovation and Technology categories at the 2009 Victorian Engineering Excellence Awards. In the Innovation category, the judges indicated the project was ‘an outstanding example of international best practice, which establishes a new benchmark for further development of high-benefit information technology systems applications, in the management of the Australian road network.’ In the Technology category the judges ‘were most impressed by the development of best practice engineering that provided a quantum shift in the integration of technology to deliver transport solutions for the greater benefit of Melbourne.’ The project was also a finalist in the 2009 Australian Engineering Excellence Awards.

Figure B-3: Fixed Time Freeway Ramp Signals - Typical Speed Contour Plot in the AM Peak

Figure B-4: HERO Freeway Ramp Signals - Typical Speed Contour Plot in the AM Peak
Figure B-5: ‘Before and after’ Austroads National Performance Indicators.

Monash-CityLink-West Gate Upgrade (M1) Project (2007 – 2010)

As part of the Monash-CityLink-Westgate freeway upgrade project, ramp signals have been installed along 75km of Melbourne’s freeway network at 64 ramps on the Princes Freeway West, Western Ring Road, West Gate Freeway, CityLink, Monash Freeway and South Gippsland Freeway.

The ramp signal sites include one, two, three and four lane ramp meters, as appropriate, to manage the entering traffic, as well as five sites with free flow priority access lanes for trucks and high occupancy vehicles. The system uses the HERO suite of algorithms with further enhancements since the initial pilot.
Attachment to Appendix B

Control of an Access Ramp to a Melbourne Freeway by Mini Computer

Kerras Burke
Melbourne and Metropolitan Board of Works, Melbourne.

ABSTRACT: The demand for freeways in most cities lags behind the supply as it takes time for the community to recognise the growth in the use of the motor car and to institute those procedures necessary for the planning, financing, construction and operation of a full hierarchy of road systems.

Those links in a freeway system which are commissioned first are most attractive to motorists, and this can result in overloading of the freeways by commuter motorists in morning and evening peak hours.

Traffic on the Gibson Street Ramp onto the South Eastern Freeway in Melbourne is regulated by traffic signals whose phases are controlled by a mini computer in accordance with traffic conditions on the freeway itself.

The equipment installed and operating principles described are applicable to a wide range of traffic engineering control situations.

KEYWORDS AND COMPUTING REVIEWS CATEGORIES: Freeway Ramp Control, 3.2, 3.8.

HISTORY
Following the construction of the first section of the four lane South Eastern Freeway for a distance of two miles between Port Road, Melbourne and Barkly Avenue, Richmond, traffic volumes built up from 26,000 vehicles per day in 1962 to 34,000 vehicles per day in 1969, and morning peak volumes increased from 2,600 to 4,000 vehicles per hour over that period.

The dispersion of vehicles at each end of the freeway was found to be the most important factor in the operation of the freeway itself.

When the freeway was to be extended a further two and a half miles eastwards in 1969, additional traffic was expected but, because of the restricted capacity at the City end, some restriction was considered necessary at one of the ramps at Richmond, where the old freeway terminal was to be converted to a ramp connection in the new scheme.

The new freeway extension was opened in May 1970. Traffic signals were installed at the entrance to the Gibson Street Ramp, Richmond, and brought under the control of a traffic responsive system early in 1971.

FREeway DEMAND
Freeways in a city are designed and located with regard to a number of factors. These include the location with respect to existing streets, the geometric (design speed) standard, the capacity of the freeway itself, and the details and loading characteristics of arterials and ramps which feed it, and into which it discharges.

The load in the morning and evening peak hour of the South Eastern Freeway is 10% of the 24 hour volume. The direction in which this occurs, and the details of peak hour traffic is most significant in conditions of travel on this freeway, as indeed on all freeways which are built in multiples of lanes — four, six or eight — these presenting a restricted choice of different capacities.

The commuter driver travelling to work by car travels a route which is based on habit, cost, convenience and time. Just when the trip is made depends on the hours of the working day, and results in a concentrated demand for road space in Melbourne between 7:30 a.m. and 4:30 p.m. When many cars endeavour to use the roads at the same time there is a reduction in the space between cars and more skill and attention is required by the driver. Delays and accidents are more likely to occur.

These conditions have been graded by the U.S. Highway Capacity manual into six levels of service varying from free flow condition 'A' down to congestion and stoppage 'F'.

New road space can be acquired by construction of freeways which have no frontage access to properties, and no surface cross roads, and can carry a large number of cars with a lower demand on the abilities of the driver.

TRAFFIC FLOW
The flow of traffic in the normal morning peak hour is shown as a diagram in Figure 1.

Two conditions are considered. First the demand, which is number of cars which would like to use the facility and then the capacity, which is the number of cars per hour which can be accepted and flow through the system without having to queue. The number of cars entering from the east on Toorak Road and the freeway extension road is limited by the contributing streets and traffic signals. This amounts to 3,000 v.p.h. At the first off ramp, the Boulevard Off Ramp, 600 v.p.h. are observed to exit, and 3,000 v.p.h. remain bound for the City.
RAMP CONTROL METHODS

There are a number of ways of metering ramps and controlling freeway traffic which are in use throughout the world, as follows:

1. After ascertaining the regular peak flows of commuter motorists, decide on a time to close the ramp each day, and then use a timer to activate "Ramp Closed" illuminated signs. Advance publicity is needed before this is commissioned.

2. Use a Volume and Occupancy Analogue Computer to operate the closure signs described above. This reacts unfavourably with regular ramp users.

3. At the nose of the ramp prior to the merging area, have a traffic signal cycling with a regular short green display. This permits only one car at a time to enter the merge area.

4. Detectors can be added to detect hazard users and withhold green until the area is clear.

5. Measure volumes, speed and lane density for use in calculating by theory the number of cars which could merge per minute, and operate traffic control signals accordingly. This is the control method adopted for this project.

6. Detect a suitable gap between cars in the kerbside lane of the freeway. As soon as the gap is detected then release a car from the ramp earlier enough for it to accelerate out to match this gap. This injection system has been used with extensive electronic equipment.

7. The Police can regulate the ramp with transmitters as communication between those operating the freeway and those at the ramp.

8. Advice from a radio announcer in a car or aeroplane can be broadcast, and studies indicate this will direct overall traffic by some 20%.

DIAGRAM SHOWING ARRANGEMENT OF RAMP CONTROL EQUIPMENT

Fig. B.2: Diagram showing the acquisition of data, location of equipment, and control of traffic in the vicinity of the access ramp.
ON STREET CONTROLLER

The traffic signal control for the ramp was placed at the nearest intersection where it was felt that motorists who were unable to proceed onto the ramp and freeway could have the option of taking a surface street if they did not wish to wait. (Figure 2).

The intersection appears superficially as a four leg intersection with East-West, West-East movements of the local area. The approach to this for ramp traffic is from three directions, a direct movement from the North, a left hand turn from the East, and a right hand turn from the West.

These are controlled by arrays of traffic signals displaying arrows in each direction of approach (Figure 3). The motorist can obey the arrow signals which let him proceed along the local street, or can wait for the arrow alongside to direct him onto the ramp leading to the freeway.

The local street controller is housed in a steel cabinet nearby.

It is a fully vehicle actuated controller supplied by the Eagle Signal Co. of Australia, Type CT 250, which has a transistorized logic and timing control. (Figure 4.)

When not "on line" to the computer, the controller functions with vehicle actuating using detector loops on the local streets and giving fixed arrow times to the ramp.

When "on line" to the computer control however, each phase is called by the computer.

There are three main phases (A1, B1 and C) for entry to the freeway from the three contributing streets. When it becomes necessary to reduce the amount of time available to enter the freeway, these phases are forced off to sub-phases which display red, but still permit local street movements with a display of green arcs.

MINI COMPUTER

The computer installed is a PDP-11 model, with a store of 4096 x 12 bit words, manufactured by the Digital Equipment Corporation, and installed by the Eagle Signal Company.

FIGURE 3. Traffic signal display at the intersection of the local streets and the Gibdon Street On Ramp to the South Eastern Freeway.

The vertical arrow lanterns indicate access to the freeway, and the horizontal arrow lanterns indicate a right turn for local street traffic.

FIGURE 4. Traffic signal control cabinet, with communication with the computer indicated on the top left corner, and the vehicle control equipment in the centre left.

FIGURE 5. Computer control console housing the computer on the top, the signal and detector input and output (at centre) and power supply at the bottom.

The input and output channels have indicator lights and test switches.
DETECTORS

There is an extensive surveillance system provided by detectors over 4,000' of freeway and at the controlled intersection and ramp. (Figure 7.)

On the freeway itself the detector stations are located 2,600' upstream of the ramp nose, and at two intermediate locations; at the nose, and 1,400' downstream of the nose.

These give advance information of freeway conditions, and information after merging of ramp and freeway streams has occurred.

The detectors consist of 8' x 4' loops of wire set into the road pavement, connected to oscillator circuits, which detect the passage or presence of the mass of metal of a car.

The right hand lane and the left hand lane have a separate detector at each station. The shoulder, or emergency stopping lane, has also a loop connected to the left hand lane detector. This supplies data for vehicles which may be forced to use the shoulder.

The detectors on the ramp itself give information of conditions on it, and whether a queue is forming.

The cable from the computer interface passes through a protective circuit, and, for expediency, was put in 1½" galvanized water pipe fastened to the back of the freeway protective guardrail. However, high summer temperatures and occasional collisions have caused fractures of junction boxes and the pipes are being put underground.

The power supply is 32 volts A.C. to the individual detector boxes. These are located on pillars for ease in servicing and adjustments.

TRAFFIC FLOW THEORY

Observations of speed and flow of vehicles show that for a given flow there can be two speeds — and on this freeway, 4,600 v.p.h. a flow at 45 m.p.h. at level of service D or 15 m.p.h. at level of service E.

It is preferable to keep to the first level, analogous to a laminar flow in hydraulics, as it gives a shorter travel time. When this condition breaks down, the congested slow condition results, and the first condition cannot be resumed until the flow (or demand) is reduced.

Each vehicle takes a certain time to pass over a detector. Then there is a gap, or headway between it and the next car that passes.

The lane density is a measure of the conditions on the freeway and is the percentage of time during which the detectors are activated by cars.

When the flow rate is at the higher speed level, the number of cars which can enter by a ramp depends on the gaps between cars on the freeway.

Reports by Bremer, Bahr, Drew and Messer in Highways Research Board Record No. 279 and by Drew, Bahr and Whitson (No. 244) utilise the gaps expected and use an Erlang distribution to allow for platoon effects. These occur because of differences in driver-car behaviour, and as this freeway has traffic signals at the entrance.

The expressions derived by these authors are from the number of critical merging gaps to be found and the chance of a ramp vehicle getting one.
AppENDix B

Ramp Service Volume \( q_r = \frac{(1 - P_0)}{E(t)} \)

Mean Delay suffered by ramp vehicles in position to merge, \( E(t) \)

\[ E(t) = \sum_{i=0}^{\frac{a-1}{0.33q}} \frac{(a_{eq})^i}{i!} \]

Ramp Service Volume

\[ a = 1 + \frac{0.33q}{q_r} \]

\[ q_r = \frac{a_{eq}^i \sum_{i=0}^{\frac{a}{0.33q}} (\sum_{i=0}^{\frac{a}{0.33q}} \frac{(a_{eq})^i}{i!})}{i!} \]

METHODS OF COMPUTATION

The state of all the detectors on the freeway and on the approach roads, and ramp is scanned at the rate of the internal strobe of the small computer (40 Hz) and the pulses and pulse trains summed to keep a count of the number of vehicles, the time to pass over the detectors, the lane density, gap size, giving both instantaneous values and long term averages.

A problem oriented language (Focal) is used to write the programme which extracts the record of the number of cars and the density at critical places on the freeway, and then calculates the time for phases of the traffic signals.

At present the calculations are relatively simple, and are a simplified form of volume and density control, based on the known capacity of the freeway, and further developments are planned.

In the peak hour there is a continuous demand for vehicles to go through the intersection leading to the ramp, consequently time has to be wasted at the signals in order to reduce the number going through. Time is 'lost' when amber and all red are displayed, and also when the green arrows to the freeway are only displayed part of the time whilst local movements are permitted.

At present a summary is made every 20 seconds of the number of cars on the freeway and ramp advance detectors. The green time of the arrows is reduced as the coast goes up.

The lane density in the densest lane at the merging area is taken and the green arrow time further reduced.

The cycle of signals is approximately 72 seconds, with phases as follows—

**MAIN PHASE**

A phase — Local Street
- 24 secs: Freeeway Arrow 24 — 4 secs. (varies)

B phase — Local Street
- 24 secs: Freeeway Arrow 24 — 4 secs. (varies)

C phase —
- Freeeway Arrow 12 — 6 secs. (varies)

**SUB PHASE**

Ambers and All Red between each phase are 2 seconds each. The green arrow to the freeway does not drop below 4 seconds because this type of control for a freeway ramp is new to the Melbourne motorist, and it is not possible to show a continuous “red” without it being mistaken for signal malfunction.

**PUBLICITY**

Little publicity has been given to the function of these signals and control.

An advance article was written in the evening newspaper some months before installation, and a press release after the system was commissioned.

Motorists had been used to entering the original freeway terminal in this area for 10 years, and it has been a slow process to educate the driver to wait for his turn to enter the ramp leading to the reconstructed freeway.

Initially the multiple arrow displays were misinterpreted, and ramp traffic entered in two lanes, and it has been necessary to construct a median strip and channelisation to correct this.

**DISCIPLINE**

This type of control is new to the city, and even abroad where the motorists are used to it, the signals are not fully obeyed as there is no physical danger to a motorist proceeding against this type of red signal.

This table shows the numbers of cars going through the intersection:

<table>
<thead>
<tr>
<th>TIME (A.M.)</th>
<th>TOTAL</th>
<th>ILLEGAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.00 to 7.15</td>
<td>245</td>
<td>13</td>
</tr>
<tr>
<td>7.15 to 7.30</td>
<td>239</td>
<td>12</td>
</tr>
<tr>
<td>7.30 to 7.45</td>
<td>279</td>
<td>26</td>
</tr>
<tr>
<td>7.45 to 8.00</td>
<td>251</td>
<td>40</td>
</tr>
<tr>
<td>8.00 to 8.15</td>
<td>307</td>
<td>128</td>
</tr>
<tr>
<td>8.15 to 8.30</td>
<td>256</td>
<td>86</td>
</tr>
<tr>
<td>8.30 to 8.45</td>
<td>348</td>
<td>95</td>
</tr>
<tr>
<td>8.45 to 9.00</td>
<td>253</td>
<td>42</td>
</tr>
</tbody>
</table>

| TOTAL | 2078 | 442 |

**FIGURE 8. TRAFFIC FLOW NORMAL CONDITIONS**

Traffic flow for normal conditions in the morning peak for ramp and for freeway combined. The density of vehicles on the freeway lanes is shown as a percentage of time for which detectors are covered by vehicles.
TYPICAL DAY OBSERVATIONS

Information obtained on typical days is shown in a diagrammatic form of the morning peak condition, the information being obtained from the teletype print out sheet, with verification by traffic counting staff where necessary. (Figure 8.)

As the volume of traffic builds up to a rate of 4,000 vehicles per hour, the installation reduces the green time to the ramp, and this partly reduces the ramp volume. There is still considerable illegal movement, in particular, turning left against a red arrow display at the head of the ramp.

The cars which are in excess of the outlet capacity cause partial queuing, and the lane density moves up from the usual 5% to 15% to 25% for the left lane, and 30% to 35% for the right lane between 8 and 9 a.m. Normal conditions do not return until the flow drops to 3,600 vehicles per hour.

A diagram has been included for abnormal days, in this case when there was a railway strike, and a more prolonged situation of high density occurs from 7 to 9 a.m. Normal conditions do not return until the flow drops to 2,600 v.p.h. (Figure 9).

FURTHER WORK

This installation has reduced delays on the freeway, but relies on signal adherence by drivers for its proper functioning at one ramp only.

As further freeways are constructed, with several ramps to feed on to traffic, it will be necessary to control these too, and connect the individual controllers so that congestion at any location can be detected and the ramp flows upstream can be regulated before stoppages occur on the freeway itself.

I expect that commuter motorists will become used to the systems and will eventually fully co-operate for mutual benefit when the objectives are fully realised.

ACKNOWLEDGEMENTS

This paper has been presented with the permission of Mr. A. H. Croxford, F.I.R., Chairman of the Board of Works, and Mr. J. H. Garner, Engineer for Metropolitan Highways.

I would like to acknowledge the support for this project from Mr. R. E. Lee, Supervising Engineer, Highway Planning of the Board, and Mr. J. D. Shaw and Mr. P. Walsh of the Eagle Signal Company.

DISCUSSION

QUESTION (G. K. Jenkins - Australian Post Office): Can you describe any fail-safe aspects of the system?

ANSWER: There are several sorts of failures which haven't got restart mechanisms. When the power goes off we have to restart it manually and also if the machine starts sending out instructions and signals, if it does go amok, then the computer drops off and we return to just the ordinary vehicle actuated system with the signals precentred at a moderate amount of throttling to the freeway.

QUESTION (R. L. Hill - IBM Australia Ltd): Is work being done on detecting gaps in the freeway traffic and timing the release of cars down the on-ramp to meet the gap?

ANSWER: This is very sophisticated control requiring a lot of detectors along the roads, perhaps half a mile in advance, and electronic equipment to find a gap and make sure that it continues and that someone doesn't cut in. Release of the car is controlled by a succession of lights flashing as he goes down so he can check in at high speed.

FURTHER QUESTION (G. K. Jenkins): Why does your control system start up at the same time each day, even during train strikes?

ANSWER: At present we run from 6:30 a.m. to 9:30 a.m. with the computer switched on at a time clock. The rest of the day the system's either switched to vehicle actuation or to flash. We tried the vehicle actuation, but there were one or two prominent residents who come in to work at ten and leave at four. We felt they were being held up so we have this system 6:30 to 9:30.
### APPENDIX C: Photometric Test Results 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.

<table>
<thead>
<tr>
<th>Degrees up from beam axis</th>
<th>Minimum luminous intensity</th>
<th>Degrees left from beam axis</th>
<th>Degrees right from beam axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>167.4</td>
<td>169.6</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>228.3</td>
<td>234.8</td>
</tr>
<tr>
<td>7.5</td>
<td></td>
<td>289.1</td>
<td>302.2</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>345.7</td>
<td>354.4</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>373.9</td>
<td>367.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Degrees down from beam axis</th>
<th>Minimum luminous intensity</th>
<th>Degrees left from beam axis</th>
<th>Degrees right from beam axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>125</td>
<td>250</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>125</td>
<td>250</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>19</td>
<td>125</td>
</tr>
<tr>
<td>7.5</td>
<td></td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>67.4</td>
<td>64.0</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>30.0</td>
<td>28.8</td>
</tr>
<tr>
<td>35</td>
<td></td>
<td>15.1</td>
<td>14.6</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>9.2</td>
<td>9.3</td>
</tr>
</tbody>
</table>

**Note:**

AS 2144 – Black  Measured Intensity – Red
PHOTOMETRIC TEST RESULTS YELLOW ATS LED

<table>
<thead>
<tr>
<th>Degrees up from beam axis</th>
<th>Minimum luminous intensity</th>
<th>Degrees right from beam axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Degrees left from beam axis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Degrees down from beam axis</th>
<th>Minimum luminous intensity</th>
<th>Degrees right from beam axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Degrees left from beam axis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note:
Note: AS 2144 – Black  Measured Intensity – Orange
<table>
<thead>
<tr>
<th>Degrees up from beam axis</th>
<th>Minimum luminous intensity</th>
<th>Degrees right from beam axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Degrees left from beam axis</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>282.6</td>
<td>284.8</td>
</tr>
<tr>
<td>10</td>
<td>441.3</td>
<td>373.5</td>
</tr>
<tr>
<td>7.5</td>
<td>500.0</td>
<td>506.5</td>
</tr>
<tr>
<td>5</td>
<td>528.3</td>
<td>567.4</td>
</tr>
<tr>
<td>3</td>
<td>552.2</td>
<td>615.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Degrees down from beam axis</th>
<th>Minimum luminous intensity</th>
<th>Degrees right from beam axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Degrees left from beam axis</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>0</td>
<td>138</td>
<td>275</td>
</tr>
<tr>
<td>3</td>
<td>138</td>
<td>275</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>138</td>
</tr>
<tr>
<td>7.5</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>10</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>15</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>20</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>25</td>
<td>41.3</td>
<td>43.5</td>
</tr>
<tr>
<td>30</td>
<td>26.8</td>
<td>27.1</td>
</tr>
<tr>
<td>35</td>
<td>23.9</td>
<td>22.6</td>
</tr>
<tr>
<td>40</td>
<td>19.6</td>
<td>19.7</td>
</tr>
</tbody>
</table>

Note: AS 2144 – Black          Measured Intensity – Green
Appendix D: Congestion Management with Ramp Signals

Management of the freeway during heavy congestion requires additional strategies which are employed outside of the HERO operation. This intervention restricts the ramp flows to values which are lower than normal operation. This operation will cause longer ramp queues which may also affect arterial roads for a limited period of time. However, the modified operation will reduce the extent of worsening congestion and facilitate faster recovery from congestion. Different strategies are progressively applied depending on the level of congestion.

As travel time algorithms consider a number of downstream detector stations it provides a valuable indication of congestion over a significant length of freeway. Operation to change the cycle time and advise motorists of long delays on the freeway are based on the ratio of the estimated travel time (ETT) to the nominal travel time (NTT) for the first travel time destination downstream of the ramp.

Five levels of congestion downstream of each ramp are identified according to the ETT/NTT ratio and conveyed by a Congestion_flag as shown in Table D1. Appropriate control of the freeway ramp signals and RC3 sign information is then implemented.

<table>
<thead>
<tr>
<th>Average Speed (km/h)</th>
<th>ETT / NTT</th>
<th>Congestion_flag</th>
<th>Change to Cycle Time</th>
<th>RC3 Freeway Condition Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 67</td>
<td>&lt; r₀</td>
<td>0</td>
<td>No change - ALINEA/HERO cycle time is applied as usual</td>
<td>Light</td>
</tr>
<tr>
<td>50 to 67</td>
<td>r₀ &lt; r₁</td>
<td>1</td>
<td>No change - ALINEA/HERO cycle time is applied as usual</td>
<td>Medium</td>
</tr>
<tr>
<td>40 to 50</td>
<td>r₁ &lt; r₂</td>
<td>2</td>
<td>Use max(ALINEA/HERO cycle time, ramp[i].congestion_cycle_time[1])</td>
<td>Heavy</td>
</tr>
<tr>
<td>25 to 40</td>
<td>r₂ &lt; r₃</td>
<td>3</td>
<td>Use max(ALINEA/HERO cycle time, ramp[i].congestion_cycle_time[2])</td>
<td>Major Delays (Flashing)</td>
</tr>
<tr>
<td>&lt; 25</td>
<td>&gt; r₃</td>
<td>4</td>
<td>Use max(ALINEA/HERO cycle time, ramp[i].congestion_cycle_time[3])</td>
<td>Seek Alt Route (Flashing)</td>
</tr>
</tbody>
</table>

**Notes:**
- rᵢ thresholds are configurable parameters at site level with default values of:
  - r₀ = 1.5
  - r₁ = 2.0
  - r₂ = 2.5
  - r₃ = 4.0
- Advisory messages, including the colour and flashing/non flashing message, shall be configurable at system level.

Table D-1: Congestion Travel Time Thresholds

The ramp[i].congestion_cycle_time[k], (k =1, 2, 3), are configurable cycle time parameters for each ramp i corresponding to each Congestion_flag. Their values should be greater than ramp minimum cycle time and less than queue control and queue override cycle times.

Specific ‘Ramp Properties’ provide the choice of assigning a fixed cycle time value to ramp[i].congestion_cycle_time[k] corresponding to each Congestion_flag, as well as providing the appropriate freeway condition message on the RC3 sign. Whenever Congestion_flag gets a value greater than 1, this module activates and overrides the HERO cycle time with min(ALINEA/HERO cycle time, ramp[i].congestion_cycle_time[k]). If the value of ramp[i].congestion_cycle_time[k] is left blank, then the ALINEA/HERO cycle time is applied as usual.

In an incident, the cycle time calculation would apply unless the ramp was closed. In this situation the incident messages would override the freeway condition message on the real time information sign.
# Appendix E: Glossary of Terms and Traffic Flow Relationships

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algorithm</td>
<td>Programmed logic sequence within the ramp metering system which transforms traffic data and operator input into traffic control commands.</td>
</tr>
<tr>
<td>Bottleneck</td>
<td>A fixed location where the capacity is lower than the upstream capacity.</td>
</tr>
<tr>
<td>Capacity</td>
<td>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.</td>
</tr>
<tr>
<td>Cycle</td>
<td>A complete sequence of signal phases.</td>
</tr>
</tbody>
</table>
| Density               | Number of vehicles per unit length of lane or roadway at a given instant in time (vehicles per km). Density = \[
\frac{\text{Flow}}{\text{Speed}}\]                                                                                                                                                                                                                                                                                                                                                           |
| Downstream            | In the direction of the movement of traffic                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 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.                                                                                                                                                                                                                                                                           |
| Flow Breakdown        | The condition where free-flowing traffic experiences significant and sudden reduction in speed, with a sustained loss of throughput.                                                                                                                                                                                                                                                                                                                                 |
| Gap                   | The time 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. Headway (s) = \[
\frac{3600}{\text{Flow (veh/h)}}\]                                                                                                                                                                                                                                                                                                                                 |
| 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.                                                                                                                                                                                                                                                                         |
| 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.                                                                                                                                                                                                                                                                       |
| Occupancy             | The proportion of time a length of roadway or traffic lane is covered by vehicles, usually expressed as a percentage. 1. Occupancy is used as a surrogate for density in control systems as it is easier to measure. 2. Occupancy values are related to the detector configuration. Therefore operational values may vary according to the detector size and spacing.                                                                 |
| Peak Hour Factor (PHF)| 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.                                                                                                                                                                                                                                                                                      |
| Shock Wave            | Shock waves are defined as boundary conditions in the time-space domain that demark a discontinuity in the flow density conditions (May 1990). 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 downstream of the moving shock wave.                                                                                   |
| Spacing               | The distance between the front ends of two successive vehicles in the same traffic lane. Spacing (m) = \[
\frac{\text{Headway (s)} \times \text{Speed (km/h)} \times 1000}{3600}\]                                                                                                                                                                                                                                                                                                                   |
Speed
The distance travelled by a vehicle per unit of time, typically expressed in metres per second or kilometres per hour.

Throughput
The total volume that is achieved at a given point during a given time period.

Upstream
In the direction opposite to the movement of traffic.

Volume
The number of vehicles passing a given point on a lane, carriageway or road per unit of time, typically expressed in vehicles per hour or vehicles per day.

Notes:
Where available, the definitions above are generally consistent with the following documents:

### Traffic Flow Relationships

<table>
<thead>
<tr>
<th>Flow (pc/h/lane) -&gt;</th>
<th>1000</th>
<th>1100</th>
<th>1200</th>
<th>1300</th>
<th>1400</th>
<th>1500</th>
<th>1600</th>
<th>1700</th>
<th>1800</th>
<th>1900</th>
<th>2000</th>
<th>2100</th>
<th>2200</th>
<th>2300</th>
<th>2400</th>
<th>2500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headway (s) -&gt;</td>
<td>3.60</td>
<td>3.27</td>
<td>3.00</td>
<td>2.77</td>
<td>2.57</td>
<td>2.40</td>
<td>2.25</td>
<td>2.12</td>
<td>2.00</td>
<td>1.89</td>
<td>1.80</td>
<td>1.71</td>
<td>1.64</td>
<td>1.57</td>
<td>1.50</td>
<td>1.44</td>
</tr>
<tr>
<td>Speed (km/h) v</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (pc/km)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>33.3</td>
<td>36.7</td>
<td>40.0</td>
<td>43.3</td>
<td>46.7</td>
<td>50.0</td>
<td>53.3</td>
<td>56.7</td>
<td>60.0</td>
<td>63.3</td>
<td>66.7</td>
<td>70.0</td>
<td>73.3</td>
<td>76.7</td>
<td>80.0</td>
<td>83.3</td>
</tr>
<tr>
<td>40</td>
<td>25.0</td>
<td>27.5</td>
<td>30.0</td>
<td>32.5</td>
<td>35.0</td>
<td>37.5</td>
<td>40.0</td>
<td>42.5</td>
<td>45.0</td>
<td>47.5</td>
<td>50.0</td>
<td>52.5</td>
<td>55.0</td>
<td>57.5</td>
<td>60.0</td>
<td>62.5</td>
</tr>
<tr>
<td>50</td>
<td>20.0</td>
<td>22.0</td>
<td>24.0</td>
<td>26.0</td>
<td>28.0</td>
<td>30.0</td>
<td>32.0</td>
<td>34.0</td>
<td>36.0</td>
<td>38.0</td>
<td>40.0</td>
<td>42.0</td>
<td>44.0</td>
<td>46.0</td>
<td>48.0</td>
<td>50.0</td>
</tr>
<tr>
<td>60</td>
<td>16.7</td>
<td>18.3</td>
<td>20.0</td>
<td>21.7</td>
<td>23.3</td>
<td>25.0</td>
<td>26.7</td>
<td>28.3</td>
<td>30.0</td>
<td>31.7</td>
<td>33.3</td>
<td>35.0</td>
<td>36.7</td>
<td>38.3</td>
<td>40.0</td>
<td>41.7</td>
</tr>
<tr>
<td>70</td>
<td>14.3</td>
<td>15.7</td>
<td>17.1</td>
<td>18.6</td>
<td>20.0</td>
<td>21.4</td>
<td>22.9</td>
<td>24.3</td>
<td>25.7</td>
<td>27.1</td>
<td>28.6</td>
<td>30.0</td>
<td>31.4</td>
<td>32.9</td>
<td>34.3</td>
<td>35.7</td>
</tr>
<tr>
<td>80</td>
<td>12.5</td>
<td>13.8</td>
<td>15.0</td>
<td>16.3</td>
<td>17.5</td>
<td>18.8</td>
<td>20.0</td>
<td>21.3</td>
<td>22.5</td>
<td>23.8</td>
<td>25.0</td>
<td>26.3</td>
<td>27.5</td>
<td>28.8</td>
<td>30.0</td>
<td>31.3</td>
</tr>
<tr>
<td>90</td>
<td>11.1</td>
<td>12.2</td>
<td>13.3</td>
<td>14.4</td>
<td>15.6</td>
<td>16.7</td>
<td>17.8</td>
<td>18.9</td>
<td>20.0</td>
<td>21.1</td>
<td>22.2</td>
<td>23.3</td>
<td>24.4</td>
<td>25.6</td>
<td>26.7</td>
<td>27.8</td>
</tr>
<tr>
<td>100</td>
<td>10.0</td>
<td>11.0</td>
<td>12.0</td>
<td>13.0</td>
<td>14.0</td>
<td>15.0</td>
<td>16.0</td>
<td>17.0</td>
<td>18.0</td>
<td>19.0</td>
<td>20.0</td>
<td>21.0</td>
<td>22.0</td>
<td>23.0</td>
<td>24.0</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Legend:
- Density (pc/km)
  - < 16 (LOS A, B, C)
  - 16 - 22 (LOS D)
  - 22 - 28 (LOS E)
  - > 28 (LOS F)

Note: High Flows (greater than 2200 veh/h) would only be achieved within short flow periods.

<table>
<thead>
<tr>
<th>Flow (pc/h/lane) -&gt;</th>
<th>1000</th>
<th>1100</th>
<th>1200</th>
<th>1300</th>
<th>1400</th>
<th>1500</th>
<th>1600</th>
<th>1700</th>
<th>1800</th>
<th>1900</th>
<th>2000</th>
<th>2100</th>
<th>2200</th>
<th>2300</th>
<th>2400</th>
<th>2500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headway (s) -&gt;</td>
<td>3.60</td>
<td>3.27</td>
<td>3.00</td>
<td>2.77</td>
<td>2.57</td>
<td>2.40</td>
<td>2.25</td>
<td>2.12</td>
<td>2.00</td>
<td>1.89</td>
<td>1.80</td>
<td>1.71</td>
<td>1.64</td>
<td>1.57</td>
<td>1.50</td>
<td>1.44</td>
</tr>
<tr>
<td>Speed (km/h) v</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spacing (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>30.0</td>
<td>27.3</td>
<td>25.0</td>
<td>23.1</td>
<td>21.4</td>
<td>20.0</td>
<td>18.8</td>
<td>17.6</td>
<td>16.7</td>
<td>15.8</td>
<td>15.0</td>
<td>14.3</td>
<td>13.6</td>
<td>13.0</td>
<td>12.5</td>
<td>12.0</td>
</tr>
<tr>
<td>40</td>
<td>40.0</td>
<td>36.4</td>
<td>33.3</td>
<td>30.8</td>
<td>28.6</td>
<td>26.7</td>
<td>25.0</td>
<td>23.5</td>
<td>22.2</td>
<td>21.1</td>
<td>20.0</td>
<td>19.0</td>
<td>18.2</td>
<td>17.4</td>
<td>16.7</td>
<td>16.0</td>
</tr>
<tr>
<td>50</td>
<td>50.0</td>
<td>45.5</td>
<td>41.7</td>
<td>38.5</td>
<td>35.7</td>
<td>33.3</td>
<td>31.3</td>
<td>29.4</td>
<td>27.8</td>
<td>26.3</td>
<td>25.0</td>
<td>23.8</td>
<td>22.7</td>
<td>21.7</td>
<td>20.8</td>
<td>20.0</td>
</tr>
<tr>
<td>60</td>
<td>60.0</td>
<td>54.5</td>
<td>50.0</td>
<td>46.2</td>
<td>42.9</td>
<td>40.0</td>
<td>37.5</td>
<td>35.3</td>
<td>33.3</td>
<td>31.6</td>
<td>30.0</td>
<td>28.6</td>
<td>27.3</td>
<td>26.1</td>
<td>25.0</td>
<td>24.0</td>
</tr>
<tr>
<td>70</td>
<td>70.0</td>
<td>63.6</td>
<td>58.3</td>
<td>53.8</td>
<td>50.0</td>
<td>46.7</td>
<td>43.8</td>
<td>41.2</td>
<td>38.9</td>
<td>36.8</td>
<td>35.0</td>
<td>33.3</td>
<td>31.8</td>
<td>30.4</td>
<td>29.2</td>
<td>28.0</td>
</tr>
<tr>
<td>80</td>
<td>80.0</td>
<td>72.7</td>
<td>66.7</td>
<td>61.5</td>
<td>57.1</td>
<td>53.3</td>
<td>50.0</td>
<td>47.1</td>
<td>44.4</td>
<td>42.1</td>
<td>40.0</td>
<td>38.1</td>
<td>36.4</td>
<td>34.8</td>
<td>33.3</td>
<td>32.0</td>
</tr>
<tr>
<td>90</td>
<td>90.0</td>
<td>81.8</td>
<td>75.0</td>
<td>69.2</td>
<td>64.3</td>
<td>60.0</td>
<td>56.3</td>
<td>52.9</td>
<td>50.0</td>
<td>47.4</td>
<td>45.0</td>
<td>42.9</td>
<td>40.9</td>
<td>39.1</td>
<td>37.5</td>
<td>36.0</td>
</tr>
<tr>
<td>100</td>
<td>1000</td>
<td>90.9</td>
<td>83.3</td>
<td>76.9</td>
<td>71.4</td>
<td>66.7</td>
<td>62.5</td>
<td>58.8</td>
<td>55.6</td>
<td>52.6</td>
<td>50.0</td>
<td>47.6</td>
<td>45.5</td>
<td>43.5</td>
<td>41.7</td>
<td>40.0</td>
</tr>
</tbody>
</table>
Appendix F: References


Traffic Engineering and Control, Ramp Metering in Auckland, November 1983, pp552-553.


