Managed Freeways
Freeway Ramp Signals Handbook

keeping victorians connected
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 freeways 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
  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
  2.1. Traditional Traffic Flow Relationships
    2.1.1. Freeway Theoretical Capacity 16
    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
    2.3.1. Probability of Flow Breakdown 21
    2.3.2. Causes of Traffic Flow Breakdown
      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
    2.3.3. Recovery from Flow Breakdown 26
  2.4 Freeway Operational Capacity
    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
    2.5.1. Resilience in Transport Systems 31
    2.5.2. Building a Resilient Freeway 31

3 Principles of Freeway Ramp Metering
  3.1. A Managed Freeway System 34
  3.2. Freeway Ramp Signals in a Managed Freeway
    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
    3.3.1. General Principles 36
    3.3.2. Entry Ramps 37
    3.3.3. Exit Ramps 37
  3.4. Ramp Metering Control
    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
    3.5.1. Satisfying Ramp Demands 41
    3.5.2. Not Satisfying Ramp Demands 42
3.6. Control Strategies and Algorithms 42

3.6.1. Effective Algorithms 42

3.7. Managing Heavy Congestion and Incidents 43

3.8. When Ramp Metering has Limited Effectiveness 46

4 Criteria for Provision of Freeway Ramp Signals 49

4.1. Existing Freeways 50

4.1.1. Background Analysis 50

4.1.2. Isolated Locations 50

4.1.3. Route Treatment 50

4.1.4. Provision at New Ramps on Existing Freeways 50

4.2. New Freeways 50

4.3. Operational Standard for New Ramp Signals 52

4.4. Freeway to Freeway Ramps 52

4.5. Designing for Future Retrofitting Ramp Signals 54

5 Freeway Traffic Data 55

5.1. Traffic Data Quality and Availability 56

5.1.1. Real Time Traffic Data 56

5.1.2. Historical Traffic Data 56

5.2. Freeway Data Stations 56

5.2.1. Data Station Locations 56

5.2.2. Detector Accuracy and Reliability 57

5.2.3. Wireless Vehicle Detectors 58

5.2.4. Detector Loops 60

5.2.5. Traffic Data to be Collected 62

5.3. Data Analysis Tools 62

5.3.1. Freeway Analysis Tool (FAT) 62

5.3.2. F1RM Tool 63

5.3.3. STREAMS Data Outputs 65

5.3.4. Spreadsheet and Charts 65

5.4. Data Analysis and Interpretation 67

6 Design of Ramp Signal Installations 69

6.1. Overview of the Design Process 70

6.2. General Approach 71

6.3. Capacity Analysis and Storage Design 71

6.3.1. Freeway and Ramp Design Flows 71

6.3.1.1. Upgrading of an Existing Freeway or a New Ramp / Freeway 72

6.3.1.2. Existing Freeway 72

6.3.2. Ramp Demand Relative to Mainline Capacity 73

6.3.3. Number of Traffic Lanes at the Stop Line 74

6.3.4. Ramp Storage Requirements 77

6.3.4.1. Desirable Standard 77

6.3.4.2. Storage Difficulties 77

6.3.4.3. Example of Capacity and Storage Calculations 78

6.3.5. Considering Ramp Queue Overflow onto the Arterial Road 79

6.4. Geometric Design and Layout of Devices 79

6.4.1. General Ramp Layout 79

6.4.1.1. Stop Line Location 79

6.4.1.2. Standard Drawings 80

6.4.2. Two Lane Entry Ramp (Drg. No. 453771) 80

6.4.3. Priority Access Lanes 82
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4.3.1. Freeflow and Partially Controlled Priority Lane (Drg. No. 541797)</td>
<td>83</td>
</tr>
<tr>
<td>6.4.3.2. Metered Priority Lane (Drg. No. 541798)</td>
<td>84</td>
</tr>
<tr>
<td>6.4.4. Three and Four Lanes at the Stop Line (Drg. Nos. 541795 &amp; 541796)</td>
<td>87</td>
</tr>
<tr>
<td>6.4.5. Freeway to Freeway Ramp Metering (Drg. No. 453912)</td>
<td>87</td>
</tr>
<tr>
<td>6.4.6. Controller Location</td>
<td>91</td>
</tr>
<tr>
<td>6.4.7. Signal Pedestals</td>
<td>91</td>
</tr>
<tr>
<td>6.4.8. Signal Lanterns</td>
<td>91</td>
</tr>
<tr>
<td>6.4.10. Ramp Detectors</td>
<td>93</td>
</tr>
<tr>
<td>6.4.10.1. Stop Line Detectors</td>
<td>93</td>
</tr>
<tr>
<td>6.4.10.2. Middle of Ramp Queue Detectors</td>
<td>93</td>
</tr>
<tr>
<td>6.4.10.3. Ramp Entrance Detectors</td>
<td>93</td>
</tr>
<tr>
<td>6.4.10.4. Queue Overflow Detectors</td>
<td>94</td>
</tr>
<tr>
<td>6.4.11. Poles for Wireless Detector Receivers</td>
<td>94</td>
</tr>
<tr>
<td>6.4.12. Ramp Control Signs and Real Time Information Signs</td>
<td>94</td>
</tr>
<tr>
<td>6.4.12.1. RC1 Warning and Regulatory Sign</td>
<td>95</td>
</tr>
<tr>
<td>6.4.12.2. RC2 Warning Sign</td>
<td>95</td>
</tr>
<tr>
<td>6.4.12.3. RC3 Sign - Real Time Information Sign</td>
<td>96</td>
</tr>
<tr>
<td>6.4.13. Other Signs</td>
<td>97</td>
</tr>
<tr>
<td>6.4.14. Pavement Markings</td>
<td>97</td>
</tr>
<tr>
<td>6.4.15. CCTV Cameras</td>
<td>98</td>
</tr>
<tr>
<td>6.4.16. Power Supply and Communications</td>
<td>98</td>
</tr>
<tr>
<td>6.4.17. Lighting</td>
<td>98</td>
</tr>
<tr>
<td>7. Operation of Ramp Signals</td>
<td>99</td>
</tr>
<tr>
<td>7.1. Legal Basis for Ramp Signals</td>
<td>100</td>
</tr>
<tr>
<td>7.2. Control Algorithms used by VicRoads</td>
<td>100</td>
</tr>
<tr>
<td>7.3.1. Dynamic Activation and Deactivation</td>
<td>101</td>
</tr>
<tr>
<td>7.3.2. Time of Day Activation</td>
<td>101</td>
</tr>
<tr>
<td>7.3.3. During Incidents and Events</td>
<td>101</td>
</tr>
<tr>
<td>7.3.4. Manual Operation</td>
<td>101</td>
</tr>
<tr>
<td>7.4. Switching on/off Signs and Signals</td>
<td>101</td>
</tr>
<tr>
<td>7.4.1. Start-up Sequence</td>
<td>101</td>
</tr>
<tr>
<td>7.4.2. Close-down Sequence</td>
<td>103</td>
</tr>
<tr>
<td>7.5. Operating Sequence and Cycle Times</td>
<td>104</td>
</tr>
<tr>
<td>7.5.1. Signal Timings</td>
<td>104</td>
</tr>
<tr>
<td>7.5.2. Minimum Cycle Time</td>
<td>104</td>
</tr>
<tr>
<td>7.5.3. Maximum Cycle Time</td>
<td>104</td>
</tr>
<tr>
<td>7.6. HERO Ramp Metering Operation</td>
<td>106</td>
</tr>
<tr>
<td>7.6.1. Overview</td>
<td>106</td>
</tr>
<tr>
<td>7.6.2. HERO Operation</td>
<td>106</td>
</tr>
<tr>
<td>7.6.2.1. Activation / Deactivation</td>
<td>107</td>
</tr>
<tr>
<td>7.6.2.2. ALINEA Core Module</td>
<td>107</td>
</tr>
<tr>
<td>7.6.2.3. Critical Occupancy Estimation Module</td>
<td>107</td>
</tr>
<tr>
<td>7.6.2.4. Queue Estimation Module</td>
<td>107</td>
</tr>
<tr>
<td>7.6.2.5. Queue Control Module</td>
<td>107</td>
</tr>
<tr>
<td>7.6.2.6. Queue Override Module</td>
<td>107</td>
</tr>
<tr>
<td>7.6.2.7. HERO Coordinated Operation</td>
<td>107</td>
</tr>
<tr>
<td>7.6.2.8. Minimum Queue Control Module</td>
<td>108</td>
</tr>
<tr>
<td>7.6.2.9. Final Ramp Flow Specification Module</td>
<td>108</td>
</tr>
<tr>
<td>7.6.2.10. Implementation Module</td>
<td>108</td>
</tr>
<tr>
<td>7.6.3. Enhancements to Provide Advanced Bottleneck Control (ABC)</td>
<td>108</td>
</tr>
</tbody>
</table>
Notations and Abbreviations

ALINEA Asservissement Linéaire d’ Entrée Autoroutière, i.e., Linear feedback control of a motorway on-ramp

ABC Advanced bottleneck control

c_r Cycle time of ramp signals (seconds)

c_a Cycle time of the arterial road / entry ramp intersection signals supplying the arriving vehicle platoon to an entry ramp (seconds)

CCTV Closed circuit television

FRS Freeway ramp signals

HERO HEuristic Ramp metering co-ordination

HOV High occupancy vehicle

JUMA Joint use mast arm

JUP Joint use pole

LED Light emitting diode

LUMS Lane Use Management System

o_c Critical occupancy

pc Passenger cars

PCE Passenger car equivalents

PFN Principal Freight Network

PHF Peak hour factor

q_us Freeway mainline flow upstream of entry ramp (veh/h)

q_cap Freeway mainline capacity at critical bottleneck (veh/h)

q_ra Ramp arrival (demand) flow (veh/h)

q_ca Ramp arrival (demand) flow in vehicle platoon during cycle time c_a (veh/h)

q_rn Metered entry ramp flow from a number of ramps (veh/h)

n_r95 Number of ramp vehicles in a 95th percentile queue (No.)

n_rMax-wait Number of ramp vehicles in a queue based on the maximum wait time (No.)

n_rMean Mean number of ramp vehicles arriving in cycle time c_a (No.)

L_rDes Length of desirable ramp storage (metres)

L_rm Length of mean ramp storage (metres)

L_r95 Length of 95th percentile ramp storage (metres)

L_vs Average length of a vehicle storage space in a ramp queue (metres)

RRPM Retro Reflective Pavement Markers

SCATS Sydney Coordinated Adaptive Traffic System

tMax-wait Maximum wait time for vehicles in a ramp queue (minutes)

v_f Mean free speed

VMS Variable Message Sign

VSLs Variable Speed Limit System

TMC Traffic Management Centre

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