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.

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.
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:
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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

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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
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 Gipps 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 Pent 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 dispersal 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 further to 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 Gipps 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 arterial streets 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 work day, and results in a concentrated demand for road space in Melbourne between 7:9 a.m. and 4:6 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, and 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 accommodated and flow through the system without having to queue.

The number of cars entering from the east from Tawra Road and the freeway extension road is limited by the contributing streets and traffic signals. This amounts to 3,600 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.
APPENDIX B

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 countermotorists, 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 works 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.

Detectors can be added to detect hesitant users and withhold green until the area is cleared.

4. 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.

5. Detect a suitable gap between cars in the kerbside lane of the freeway. As soon as the front car passes the detector, the ramp is closed immediately afterward to match this gap. This injection system has been used with extensive electronic equipment.

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

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

SOUTH EASTERN FREEWAY - MELBOURNE

FIGURE 1: Diagram comparing the initial demand of traffic upon the opening of the reconstructed terminal and extension of the South Eastern Freeway with the capacity available for an acceptable level of service.

At the on ramp, the Gibbon Street Ramp, there was a demand for 1,500 v.p.h. when the new construction was completed, which is the capacity of the contributing streets and traffic signals in Richmond. This would lead to a demand for 3,000 + 1,500 = 4,500 v.p.h. in the western end of the freeway at that time.

The capacity of the western end of the freeway is limited to 4,000 v.p.h. for the following reasons:

1. The merging manoeuvre of vehicles off the ramp with through traffic reduces the rate of flow of both.
2. The older part of the freeway itself, constructed 10 years ago, has a geometry suitable for 45 m.p.h. speeds, whereas 60 m.p.h. is that of the new eastern end.
3. Breakdown lanes are absent, which has a restrictive effect psychologically and physically when breakdowns of cars occur which is common with the larger number of cars passing through.
4. At the Moorhead Overpass over Punt Road where there is a 4% up gradient, a lack of a breakdown lane for slow driving or stalled vehicles, and queues from the outlets.
5. At the western outlet, which is the Melbourne City Council area, there are three outlets which are busy roads, and when these are full, cause queues on the overpass structure.

As there can be a demand for 4,500 v.p.h. (at level of service F) but a capacity for 4,000 v.p.h. (at level of service D) there has to be a reduction of 500 v.p.h. or else a queue will form on the freeway - stretching in that hour for a mile and a half.

Therefore, the level of service to an acceptable level has been accomplished by restricting the Gibbon Street Ramp's traffic signals dependent on the conditions on the freeway from 1,500 v.p.h. demand to 1,000 v.p.h. nominally.

Diagram showing Arrangement of Ramp Control Equipment

FIGURE 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 to 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 Falcon 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 arrows.

MINI COMPUTER

The computer installed is a PDP-11 Model 51, with a store of 4096 x 12 bit words, manufactured by the Digital Equipment Corporation, and installed by the Falcon Signal Company. (Figure 5.)

FIGURE 3. Traffic signal display at the intersection of the local streets and the Gibbon 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.
It is housed in a small brick building beside the access ramp itself. The roof and floor are of concrete, with a timber false floor and a standard fireproof door to deter vandalism.

This location enables the operator to step outside and view the freeway and ramp merging area, and to see the traffic queues and signal discipline at the controlled intersection. (Figure 6.)

**FIGURE 6.** The cabin housing the computer, communication console and teletype is located between the ramp and freeway so that traffic conditions can be observed.

It is also halfway between upstream and downstream traffic detectors and close to the local street controller, thus minimising the lengths of cable.

The interface equipment is housed in a cabinet, together with ramp displays and testing switches, and the computer itself.

A teleprint model ASR 33 is used for loading and modifying programmes and for obtaining a log of operations.

**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 ¾" galvanised water pipe fastened to the back of the freeway protective guardrail. However high summer temperatures and occasional collisions has 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.

**FIGURE 7.** At the nose of the ramp where it joins the freeway there are wire loops set in the pavement and connected to detectors in a box which can be seen behind the traffic sign.

**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 and 55 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 reattained 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 lane area 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, Buhl, Drew and Messer in Highways Research Board Record No. 279 and by Drew, Buhl 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

\[ q_r = \frac{(1 - P_o)}{E(t_a)} \]

Mean Delay suffered by ramp vehicles in position to merge,

\[ E(t_a) = \frac{c}{a - 1} \sum_{i=0}^{a-1} q^i \left( \frac{(aqT)^i}{i!} \right) \]

Ramp Service Volume

\[ q_r = \frac{0.33q}{a} \sum_{i=0}^{n} q^i \left( \frac{(aqT)^i}{i!} \right) \]

Where \( q \) is the volume flowing in the kerbside lane of the freeway, \( a \) is the Erlang Parameter which defines the headway distribution of the kerbside lane system.

T is the critical gap for merging.

\( P_o \) is the chance of a ramp arrival finding the ramp empty. It is adopted as 0.56, or 0.33 chance of finding a vehicle ahead of it trying to merge.

This reduces to

\[ q_r = \frac{0.33q}{a} \left[ 4.5qT^2 + 3qT + 1 \right] \]

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 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:

B phase — Local Street

- 24 secs:

C phase —

SUB PHASE

Freeway Arrow 24 — 4 secs. (varies)

Freeway Arrow 24 — 4 secs. (varies)

Freeway Arrow 12 — 6 secs. (varies)

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>TUESDAY 3/8/1971</th>
<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>
<td></td>
</tr>
<tr>
<td>7.15 to 7.30</td>
<td>239</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>7.30 to 7.45</td>
<td>279</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>7.45 to 8.00</td>
<td>251</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>8.00 to 8.15</td>
<td>307</td>
<td>128</td>
<td></td>
</tr>
<tr>
<td>8.15 to 8.30</td>
<td>256</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>8.30 to 8.45</td>
<td>348</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>8.45 to 9.00</td>
<td>253</td>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>

TOTAL FLOW ON FREEWAY

<table>
<thead>
<tr>
<th>TIME</th>
<th>FREEWAY ARROW 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.00</td>
<td>2678</td>
</tr>
<tr>
<td>7.15</td>
<td>442</td>
</tr>
</tbody>
</table>

Figure 8: 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.
APPENDIX B

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 7% 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 graph has been included for abnormal days, in this case where 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 obedience by drivers for its proper functioning at one ramp only.

As further freeways are constructed, with several ramps to feed on 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 system 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. Cronk, I.E.R., Chairman of the Board of Works, and Mr. J. H. Garrett, 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. I. 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 pre-centred at a moderate amount of throttling on the freeway.

QUESTION (R. J. 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 a very sophisticated control requiring a lot of detectors along the road, 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 by 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>
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<td></td>
<td>373.9</td>
<td>367.4</td>
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<th>Degrees left from beam axis</th>
<th>Degrees right from beam axis</th>
</tr>
</thead>
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</tr>
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<td>14.6</td>
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<td>40</td>
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<td>9.2</td>
<td>9.3</td>
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Note: AS 2144 – Black  Measured Intensity – Red
# PHOTOMETRIC TEST RESULTS YELLOW ATS LED

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<th>Minimum luminous intensity</th>
<th>Degrees left from beam axis</th>
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**Note:**
Note: AS 2144 – Black       Measured Intensity – Orange
## PHOTOMETRIC TEST RESULTS GREEN ATS LED

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<td>19.6</td>
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</tr>
</tbody>
</table>

**Note:**
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; r_0</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>r_0 – &lt; r_1</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>r_1 – &lt; r_2</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>r_2 – &lt; r_3</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; r_3</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:
- r_i thresholds are configurable parameters at site level with default values of:
  - r_0 = 1.5
  - r_1 = 2.0
  - r_2 = 2.5
  - r_3 = 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><strong>Algorithm</strong></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><strong>Bottleneck</strong></td>
<td>A fixed location where the capacity is lower than the upstream capacity.</td>
</tr>
<tr>
<td><strong>Capacity</strong></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><strong>Cycle</strong></td>
<td>A complete sequence of signal phases.</td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>Number of vehicles per unit length of lane or roadway at a given instant in time (vehicles per km).</td>
</tr>
</tbody>
</table>
|                       | \[
| Density               | \[
|                       | $\text{Density} = \frac{\text{Flow}}{\text{Speed}}$                                                                                     |
| **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)           | \[
|                       | $\text{Headway (s)} = \frac{3600}{\text{Flow (veh/h)}}$                                                                                  |
| **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)           | \[
|                       | $\text{Spacing (m)} = \frac{\text{Headway (s) x Speed (km/h) x 1000}}{3600}$                                                             |
### Notes:

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


### Traffic Flow Relationships

#### Flow - Headway - Speed - Density - Spacing

<table>
<thead>
<tr>
<th>Flow (pc/h/lane)</th>
<th>Headway (s)</th>
<th>Speed (km/h)</th>
<th>Density (pc/km)</th>
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<td>30</td>
<td>33.3</td>
</tr>
<tr>
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<td>3.27</td>
<td>40</td>
<td>25.0</td>
</tr>
<tr>
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<td>50</td>
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<td>60</td>
<td>16.7</td>
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<td>70</td>
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</tr>
<tr>
<td>2500</td>
<td>1.44</td>
<td></td>
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</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.
Appendix F: References


http://www2.napier.ac.uk/euramp//


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


For further information please phone 13 11 71
or visit vicroads.vic.gov.au