Guide to Traffic Management Part 9

Traffic Operations

Austroads

Guide to Traffic Management Part 9: Traffic Operations

Austroads

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Guide to Traffic Management Part 9: Traffic Operations

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Abstract

The Austroads Guide to Traffic Management consists of 13 parts and provides a comprehensive coverage of traffic management guidance for practitioners involved in traffic engineering, road design and road safety.

Guide to Traffic Management Part 9: Traffic Operations is concerned with the day-to-day operations that support the provision of road services to road network users. It introduces the concept of traffic operations as underpinning road user services, covers the major types of services provided and outlines the role of intelligent transport systems (ITS) in delivering these services.

Part 9 provides guidance on the configuration and operation of systems, both ITS and manual, supporting traffic operations including network monitoring systems, incident management, traffic signal systems, congestion management, freeway/motorway management systems and traveller information systems.

Keywords

Traffic management, road network, area traffic control, traffic monitoring, incident management, incident detection, traffic signal, smart motorway, priority traffic, traffic lane, travel information, special event, intelligent transport systems

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Edition 3.1 of the Guide has been updated with Safe System content, including:

- New Section 2.2 Traffic Operations and the Safe System and Section 6.2 Intersection Signals and the Safe System
- Additional Safe System content in Sections 3.1, 3.5.4, 3.6, 3.7, 6.5.3, 6.8.2, 7, 7.3.1, 7.3.3,7.4.3, 8.1.1, 8.1.3, 8.3, 8.4.5.
- Updating the reference list and cross references throughout.

About Austroads

Austroads is the peak organisation of Australasian road transport and traffic agencies.

Austroads' purpose is to support our member organisations to deliver an improved Australasian road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

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1. Introduction

Part 9 of the Austroads Guide to Traffic Management has been given the title Traffic Operations to define the limits on its scope within the contexts of:

- the 13 different parts of the Guide to Traffic Management
- other Guides spanning the range of Austroads publications.

The structure and content of the 13 parts of the Guide is discussed in Part 1: Introduction to Traffic Management (Austroads 2019a). The 13 parts are outlined in Table 1.1.

In the context of the Guide, Part 9: Traffic Operations addresses the day-to-day operations supporting the provision of road services to road network users. Traditionally, these activities include the operation of traffic signal systems, congestion management, freeway/motorway management systems, incident management, traveller information systems and the like. Part 9 addresses the need for and operation of these systems and others from the perspective of the user services they deliver.

The scope of Part 9 is therefore the day-to-day operations that support the provision of road services, focussing particularly on those falling within the traffic management ambit of this Guide. It covers the principles underpinning the provision of road user services, the major types of services provided, the role of intelligent transport systems (ITS) in delivering these services, and provides guidance on the configuration and operation of systems, both ITS and manual, in common use in Australia and New Zealand.

Part 9 does not address the provision of static devices used to manage ongoing road and traffic conditions; this is addressed elsewhere (Parts 5, 6 and 10 of the Guide).

Table 1.1: Parts of the Guide to Traffic Management

Part	Title	Content
Part 1	Introduction to Traffic Management	Introduction to the discipline of traffic management. Breadth of the subject and the relationship between the various parts of the Guide.
Part 2	Traffic Theory	An introduction to the characteristics of traffic flow and the theories, models and statistical distributions used to describe many traffic phenomena. Processes that practitioners should consider.
Part 3	Traffic Studies and Analysis	Traffic and transport data collection surveys and studies. Traffic analysis for mid-block situations (including freeways/motorways). Analysis of signalised and unsignalised intersections, including roundabouts.
Part 4	Network Management	Broader issues and aspects of managing networks of roads to provide effective traffic management for all road users. Network needs of freight, public transport, pedestrians, cyclists, motorcyclists and private motor vehicles. Network management objectives, operating objectives, network performance measures.
Part 5	Road Management	Focus on managing mid-block traffic conditions. Good practice for access management, allocation of space to various road users, lane management. Application of speed limits.
Part 6	Intersections, Interchanges and Crossings	Types of intersection. Selection of intersection type and appropriate use. Traffic considerations in traffic management for intersections, interchanges and other crossings.
Part 7	Traffic Management in Activity Centres	Planning and traffic management of activity centres and associated transport nodes. Principles for various types of centre.
Part 8	Local Area Traffic Management	Principles and processes. Issues and resources. Selection of schemes and treatments. Design and implementation of schemes and devices.
Part 9	Traffic Operations	Applications used in traffic operations. Current practice for common systems including: traffic signals, congestion management, incident management, traveller information. Smart motorway. Manual systems used in these application areas. Event management. Information management issues and principles. Related systems integration and interoperability issues.
Part 10	Traffic Control and Communication Devices	Signing and marking schemes. Traffic signs, static and electronic. Pavement markings and delineation. Traffic signals and islands.
Part 11	Parking	Parking policy. Demand and supply. Data and surveys. On-street and off-street. Types of parking and parking control.
Part 12	Traffic Impacts of Developments	Relationship to road level of service and access management. Development profile and trigger points for treatment. Traffic impact assessment.
Part 13	Road Environment Safety	Principles and management of the safety of road environments within a traffic management context. Links to relevant sections of the GRD (Guide to Road Design) and GRS (Guide to Road Safety).

2. Objectives and Principles

2.1 Objectives

Traffic operations are critical to the implementation of network management objectives and plans (discussed in Part 4, Austroads 2016a). In a broad sense, traffic operations can be said to be directed to the maintenance of optimal traffic conditions on the road network with the following objectives:

- maximising operational safety and efficiency of the road network
- minimising negative impacts caused by recurring congestion or non-recurring incidents within the road network
- providing road users with information necessary to help support their judgement on travel and reduce stress while driving
- providing the desired level of service to priority road users.

2.2 Traffic Operations and the Safe System

The Safe System is an approach to road safety that is the basis of strategies and action plans to reduce road trauma in Australia and New Zealand. Ultimately the aim is to eliminate deaths and serious injuries resulting from crashes on the road network.

The Safe System approach is based on the following principles:

- People make mistakes – some crashes are unavoidable despite a focus on preventative measures.
- Our bodies are vulnerable – There are limits to the amount of force our bodies can tolerate before we are injured. In a Safe System, when a crash occurs the forces are managed so that they do not lead to death or serious injury.
- Road safety is a shared responsibility – This includes those involved in the planning, design, operation and management of the road system, in addition to all road users.

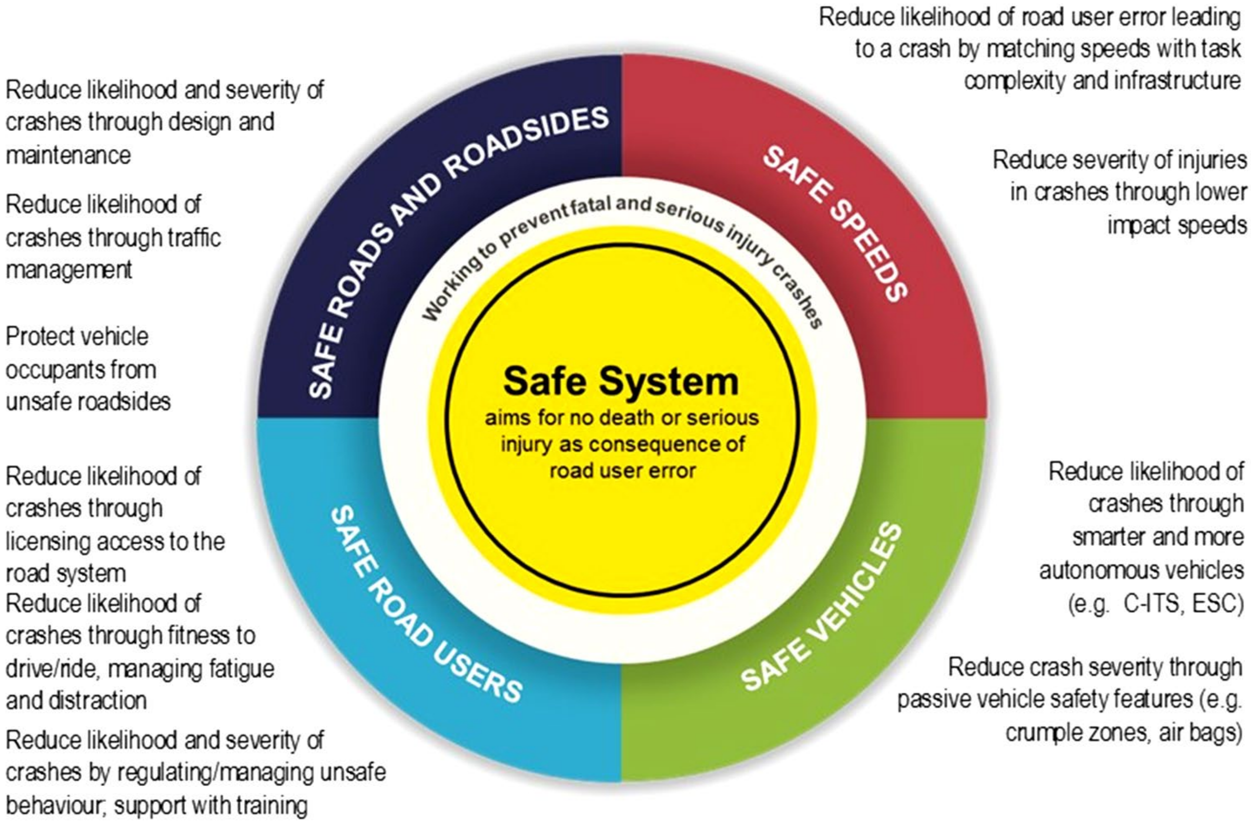
As the name suggests, the Safe System is a systems approach which recognises that the components are interrelated and must work together to achieve the desired goals. The four elements or pillars of a Safe System are:

- **Safe roads and roadsides** – Roads should be designed, operated and maintained so that they are predictable, self-explaining and encourage safe travel speeds. When a crash occurs, they should be forgiving to ensure that the likelihood of death or serious injury is minimised.
- **Safe speeds** – Operating speeds should be managed so that crash likelihood is low and, in the event of a crash, the impact forces are within human tolerances.
- **Safe vehicles** – Vehicles should incorporate design features and technology that minimise the likelihood of crashes and protect road users (including pedestrians and cyclists) when crashes do occur.
- **Safe road users** – All users should be alert, comply with road rules and engage in safe behaviour. They are supported through education, information, enforcement of road rules, training and licensing.

Operating the road network in a safe manner is a key responsibility of road agencies under the Safe System. Historically, there has been a mindset that transport mobility and road safety are competing objectives and that there is a need to trade off one against the other. The contemporary approach is to strive for safe mobility. While this may seem to present significant challenges to road agencies that have to manage multiple objectives, efficiency of movement and safety are interrelated. Incidents, particularly severe crashes that may result in injuries or death, can have major consequences and will quickly erode any efficiency benefits that might be gained by operating the network at a higher level of safety risk. There are also opportunities for new and innovative ways of operating the road network that have both efficiency and safety benefits. Intelligent transport technologies, in particular, are critical tools that are being increasingly utilised to move towards safe mobility.

Consideration of the Safe System (as represented by Figure 2.1) shows that traffic operations have direct links to all four pillars. Linkages to the Safe System and appropriate safety considerations are discussed throughout this Guide.

Figure 2.1: Holistic approach to achieving the Safe System vision



Source: based on Australian Transport Council (2008), Ministry of Transport (2010) and Office of Road Safety (2009).

2.3 Road User Support

A road user perspective lies at the heart of what the World Road Association (PIARC) terms the 'the big shift' – the transition in road administrations from the main goal of building and maintaining road networks to one of road network operations providing services to road users. The shift is typically a two-stage process (World Road Association 2003) involving:

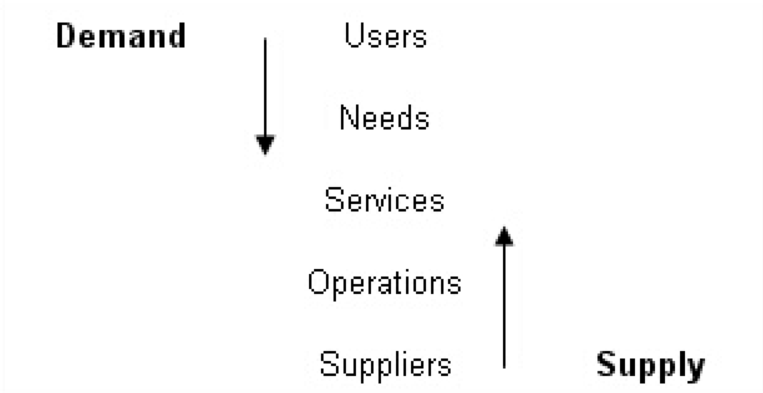
- transitioning from road construction and maintenance to road network optimisation
- shifting from road network optimisation to road network user support.

The first shift focuses on transitioning from building roads to the optimising the use of existing roads or road networks. This optimisation is typically achieved by better traffic management, whether at a road segment, network or intersection scale (Parts 4, 5 and 6 of the Guide to Traffic Management respectively, Austroads 2016a, 2019b and 2019c).

The second shift is from road network optimisation (essentially traffic management) to the support of road network users (i.e. support for traffic participation or traveller information). It lies at the heart of traffic operations. It constitutes a shift in emphasis in the way traffic management and operations and related activities are seen. The traffic manager sees good traffic management as leading to better optimisation of the network, whereas the road user who 'participates in traffic' is interested in network optimisation in only an abstract way (if at all), but is interested in the 'services' provided by the traffic operations manager.

This service oriented view underpins the way traffic operations are looked at and managed. The traffic manager's view and traffic operations are essentially in the supply domain (Figure 2.2). This is consistent with traffic management being in large part aimed at maximising the availability of road capacity. Road users and their needs on the other hand are clearly demand oriented. The interface between the demand and supply domains is where the services are positioned.

Figure 2.2: Road user support



Source: Adapted from World Road Association (2003), Figure 2.3.

To meet the requirements of road users it is important to understand how the various road user groups identify and rank the road service attributes. Austroads (2006) research showed that reliability and travel time are consistently the most important attributes across all three types of road users that the road manager can influence (Table 2.1). Commuters regard speed as a somewhat important attribute. Of the public transport attributes that road managers can influence, results from other surveys have found that reliability was the most important attribute followed by travel time and ease of access to stops.

Table 2.1: Relative importance and ranking of categories of road service attributes by user group

Attribute	Commuter	Freight	Public transport
Travel time	1 – highest	1 – highest	2
Reliability	1	1	1 – highest
Ability to maintain schedules	–	2	–
Speed	2	3	–
Accessibility/B-double network coverage	3	4	3 – lowest
Traffic signals	4	5	–
Unexpected or temporary delays	5 – lowest	6 – lowest	–

Source: Austroads (2006).

2.4 Role of ITS

Road user support services are often, but not necessarily, delivered by intelligent transport systems (ITS) applications. ITS draw upon and integrate advanced information processing, telecommunications and electronics technologies. ITS may contribute to safer and more efficient transportation systems for both travellers and freight, in either urban centres or rural areas. ITS also provide useful information in real time to motorists and commercial operators as well as road network operators.

ITS applications can be grouped into families of services, one such grouping being shown in Table 2.2. While ITS provide important technologies to support traffic operations, ITS and operations are not identical concepts. There are operational issues which have little or no relation to the technologies of ITS and some operational applications which are not ITS-based (e.g. manually implemented off-centre operation or tidal flow). Conversely, not all ITS components relate to operation.

Table 2.2: Some/typical user services provided by ITS

User information	Traffic management
Traveller information (en route or pre-trip) Route guidance and navigation Ride matching and reservations Traveller services and reservations	Traffic control Incident management Travel demand management Environmental conditions monitoring Operations and maintenance Automated dynamic enforcement Non-vehicular road user safety Multi-modal junction control and safety Enforcement
Public transport	**Electronic payment**
Public transport management En route transit information Demand responsive transport Public travel security Priority system	Electronic payment services
Commercial vehicle operations	**Emergency management**
Electronic clearance Automated roadside safety inspections On-board safety monitoring Administrative processes Commercial fleet management Inter-modal freight management	Emergency notification and personal security Hazardous material incident response Emergency vehicle management Disaster response and management
Advanced vehicle controls and safety systems	**Data warehousing services**
Collision avoidance (on-board vehicles) Collision avoidance (infrastructure) Sensor-based driving safety enhancements Safety readiness Pre-crash restraint deployment Automated vehicle operation	Weather and environmental data management Archived data management

Source: World Road Association (2003).

The role of ITS in providing services in the traffic control area has a long history in Australasia, with traffic control systems such as SCATS (the Sydney Coordinated Adaptive Traffic System) being progressively implemented in many Australasian cities since the 1970s, and freeway and motorway management systems and incident management systems more recently being rolled out.

ITS have an equally significant role in demand management by providing a greater quantity and diversity of information, thus allowing users (motorists, commercial operators and public transport customers) to make informed travel decisions based on such factors as traffic conditions, road maintenance or construction work that potentially impact their travel time, and weather conditions that affect the road network and safety. This information is becoming increasingly available through traditional media like radio and television and, more recently, online over Internet dedicated tools.

3. Traffic Operations Services, Measures and Tools

3.1 Fields of Service

From a road user support perspective, the main fields of road network operations are (World Road Association 2003):

- network monitoring (Section 3.4)
- maintaining road serviceability and safety (Section 3.5)
- traffic control (Section 3.6)
- travel aid and user information (Section 3.7)
- demand management (Section 3.8).

Additionally, it is important to note that:

- enforcement, which is not usually a road agency function, can be a critical element affecting the success of traffic operations (Section 3.9)
- network operations projects often span several functions that may be implemented together when considering ITS, other tools or projects in any of the functional areas, functional integration may be an issue (Section 3.10).

These categorisations help identify services that can be provided. They also assist in determining systems and tools that can support these services.

Network monitoring and traffic control and, to a lesser extent, maintaining road serviceability and safety are related to network optimisation in the traffic management sense. They are also relevant to road network user support, as is travel aid and user information. Demand management extends considerations from a road network user support base to broader notions of transport user support. This progression is illustrated in Table 3.1.

While safety is specifically referenced in only one of the main fields of service, in practice, all aspects of road network operations potentially impact on road safety and need to be considered in the context of the principles of the Safe System approach (Section 2.1). Links between the Safe System pillars and the main fields of network operations are as follows:

- Safe roads and roadsides: network monitoring, traffic control, demand management
- Safe speeds: traffic control, travel aid and user information
- Safe road users: traffic control, travel aid and user information, demand management (through use of safe travel modes)
- Safe vehicles: travel aid and user information (particularly C-ITS).

Table 3.1: Traffic operations fields

	Road network optimisation	Road user support	Transport user support
Network monitoring	✓	✓	✓
Traffic control	✓	✓	✓
Maintaining road serviceability and safety	✓	✓	✓
Travel aid and user information	–	✓	✓
Demand management	–	–	✓

3.2 Range of Services

The range of services that can be provided in a comprehensive network user support service is shown in Table 3.2. Note that in this tabulation not all functions and services are relevant to traffic management in its traditional sense, nor do all road and traffic agencies directly provide all services. Some are the province of other organisations (e.g. police, ambulance, fire brigade). The full range of support services is listed here for completeness.

Table 3.2: Traffic operations services

Mission	Function	Services
Network monitoring	Monitoring of traffic conditions	Data and information gathering Patrolling Data management Traffic control centres Crisis coordination centre
	Monitoring of natural events	Winter conditions (black ice, freezing rain) Fog Others (floods, cyclones, bush fires, landslides)
Maintaining road serviceability and safety	Emergency response operations	Incident management Operational services Emergency rescue (medical, mechanical) Emergency information Assistance and empathy (traffic blockage events)
	Weather related operations(1)	Winter operations (snow clearing, salt spreading where applicable) Other atmospheric extremities Road closure/blockage management
	Organisation of planned actions(1)	Pavement maintenance and roadwork Maintenance and operation Equipment maintenance
	Characteristics of the existing infrastructure(1)	Road section Hard shoulder Interchanges, exits Bridges Tunnels Toll plazas General comfort Safety devices Environmental aspects

Mission	Function	Services
Traffic control	Preventive actions	Link management Lane assignment Speed regulation Access regulation Freight traffic management Network management Rerouting plans Storing vehicles on the network Traffic signal management Advisory diversion operations Traffic management centres
	Corrective actions	Incident management Congestion management Traffic management plans Operation teams
Travel aid and user information	Predictive information	Long term information Comfort information Travel times
	Real-time information	Traffic information centres In-vehicle services (radio, route guidance) Infrastructure oriented (variable message signs (VMS)) Re-routing advices Warnings (congestion, weather)
	Miscellaneous travel aid	Comfort services: • refuelling • restaurants, snacks, motel • shops • hygiene and comfort • facilities for people with disabilities • general information. Infrastructure oriented: • signs • other roadside equipment • rest and parking areas.
Demand management	Infrastructure oriented	Multimodal infrastructure (freight, park and ride) Bus lanes, high occupancy vehicle (HOV) lanes
	Actions promoting modal shift	Park and ride management Multimodal information Multimodal transfer management
	Payment systems	Electronic fee collection (EFC) Electronic toll collection (ETC) Variable pricing

1 *Services related to these functions do not form part of traditional notions of traffic management, but do form part of the broader scope of road network operations.*

Source: Adapted from World Road Association (2003).

3.3 Organisational Framework

From the range of services comprising a comprehensive road user support service, it will be apparent that a coordinated effort from several areas within any road agency will be required. Consequently, coordination with external agencies will be essential. This is best illustrated by considering incident management.

Inter-agency coordination and cooperation facilitates efficiency in incident management operations. Agencies involved in traffic incident management include:

- organisations responsible for road traffic and transport
- police
- fire, rescue and ambulance services
- road and traffic service providers
- response, towing and recovery providers
- environmental monitoring and hazardous materials safety
- utility service providers
- media.

Usually the lead agencies for traffic incident management initiatives are road agencies and police services. Typical arrangements for the roles and responsibilities of each agency are summarised in Table 3.3. The range of functions performed by each stakeholder highlights the importance of inter-agency coordination.

Table 3.3: Typical agency roles and responsibilities for incident management

Stakeholder	Roles and responsibilities(1)	
Police	Provide emergency call centre, coordinates communications. Assume role of Incident Commander, supervise response actions. Secure incident scene, safeguarding property. Perform first responder duties. Assist responders in accessing the incident scenes.	Control arrival and departure of incident responders. Police perimeter of incident scene and impact area. Conduct crash investigation. Perform traffic control. Establish emergency access routes. Ensure responder safety.
Fire and rescue	Rescue/extricate victims. Extinguish fires.	Contain or mitigate the release of hazardous materials.
Emergency medical services	Provide triage, medical treatment to those injured at the incident scene. Determine destination and transportation requirements for injured victims.	Transport victims for additional medical treatment.
Road agencies (Similarly for local authority for non-state roads and toll road operators for toll roads)	Protect incident scene. Implement traffic control strategies and provide supporting resources. Monitor traffic operations. Disseminate motorist information. Mitigate incidental vehicle fluid spill confined to the roadway. Assess and direct incident clearance activities.	May perform first responder duties (service patrol). Clear minor incident (service patrol). Perform incident detection and verification (service patrol/TMC). Develop and operate alternative routes. Assess and perform emergency roadwork and infrastructure repair. Inform road users with updated traffic information.
Towing and recovery	Recover vehicles and cargoes. Remove disabled or wrecked vehicles and debris from incident scene.	Mitigate non-hazardous material (cargo) spills.

1 *Table 3.3 shows typical agency roles and responsibilities. However, detailed operational arrangements between organisations may differ between jurisdictions.*

Source: Austroads (2007a).

Coordination arrangements between agencies should not be based on informal understandings. As responding agencies have different goals, perspectives, responsibilities, priorities and operating cultures, this may result in misunderstandings, disagreements, delays, and inefficiencies in resolving traffic incidents. Establishing formal agreements or memoranda of understanding can help minimise these differences.

Formal agreements may cover desired joint outcomes, roles and responsibilities, governance, incident command structure, equipment staging, traffic control, hazardous materials incident issues and procedures, crash investigation procedures, quick clearance procedures. Performance goals may also be set as part of formal agreements, such as incident response and clearance times.

For further guidance on organisational issues related to incident management, refer to Commentary 1 and *Traffic Incident Management: Best Practice* (Austroads 2007a).

[see Commentary 1]

This section focused on incident management as an example to discuss institutional arrangements. However, similar comments apply to other areas of road user support where inter-agency coordination is required.

3.4 Network Monitoring

Network monitoring enables an operator to observe the condition of the network and its use as quickly and completely as possible. There are two dimensions to this: monitoring traffic conditions and monitoring natural events. Table 3.4 summarises objectives, tools, equipment and outcomes for network monitoring, and lists some considerations. Key elements are discussed in more detail in the ensuing sections.

Table 3.4: Network monitoring – summary

Objectives	Equipment	Tools	Outcomes	Considerations
Get information about: • traffic conditions • weather conditions • types and status of vehicles • road and driver.	Detectors. CCTV. Probe vehicles. Tag readers. Mobile device. Bluetooth devices.	Video processing. Detection algorithms. Traffic simulation. Algorithms and models.	Better understanding and response for conditions. Better decision making. Promote better coordination between parties. Accumulation of data.	Some detectors require accurate installation. Balance between purpose, data volume and communication bandwidth. Planning and coordination about the use and the collection method is essential. Privacy and legal issues.

Source: Adapted from World Road Association (2003).

3.4.1 Services

ITS-based monitoring systems are commonly characterised by the use of electronic sensors, data processing by a central computer, and data transmission. The detailed system requirements are heavily dependent on the operations missions to be supported and the road network structure under consideration. Further, when an existing monitoring system or detection technologies need to be incorporated into a new monitoring system, it is important to evaluate the system applicability for continued use and whether new requirements can be satisfactorily accommodated.

Although monitoring is an integral part of any ITS service, it usually does not provide any service on its own. The major roles (or sub-services) of network monitoring can be summarised as:

- monitoring traffic, incidents and road environmental conditions
- supporting road network operators in making decisions on how to better operate the network
- monitoring and evaluating operations functions
- accumulating and archiving data for off-line analysis.

Each of the services (or sub-services) described are realised through various measures.

Monitor traffic conditions

Traffic condition monitoring aims to either detect or predict disturbances from normal traffic conditions, whether caused by incidents or otherwise arising from unusual congestion, as quickly as possible, in order to take prompt remedial action. The prime performance measures are detection delay (the interval between the time the incident occurs and the time the management service is warned of this incident) and the reliability of the information collected.

A subsidiary aim is to collect traffic characteristics (e.g. flow, occupancy rate, speed) to an appropriate level of detail in order to monitor or anticipate trends. The required qualities are reliability and completeness of coverage of the collection systems.

Traffic monitoring thus requires:

- systems for the collection, processing and centralisation of traffic data and information
- formal relationships with the safety and emergency call-out services or the assistance services in order to minimise detection delay
- automatic or non-automatic warning systems (emergency call network, automatic incident detection)
- organisation of regular surveillance patrols on the most sensitive roads.

Monitor environmental conditions

Monitoring natural events aims to detect or predict abnormal natural situations (weather or other) likely to affect the level of service of the network, in particular its safety of use. This ideally requires both detection and the integration of measurements or information into traffic prediction models, although the latter is not yet common in Australia or New Zealand.

Detection systems inform the operator of the onset (or probability of onset) of difficult weather conditions (such as fog, black ice, snowfalls, rain storms, cyclones) or other unfavourable natural events (landslides, floods, bush fires and the like), and permit the generation of appropriate advice to road users.

Support decision-making

Network monitoring systems must support decision-making. Operator responsibilities are diverse including monitoring of traffic and environmental information, decision-making on the severity of incidents, selecting and prioritising operational functions and liaison with coordination groups. These processes need to be done in a short time period in response to the occurrence of incidents. System integration in the network operation centre is therefore important in order to support decision-making processes.

Monitor and evaluate operations functions

Network monitoring systems must support the monitoring and evaluation of other operations functions. The impacts of operations activities are monitored and evaluated to determine further actions. A closed loop of information involving monitoring, decision-making and evaluation of resulting impacts is thus maintained.

Examples of measurement and evaluation tools available to assist this task in the Australian and New Zealand context include (Austroads 2007b):

- tools within the SCATS and STREAMS traffic control systems
- ARTIS (Automatic Real-time Traffic Information System)
- TRIPS (for Travel Reporting and Integrated Performance System)
- ARRB travel time model
- VicRoads Freeway Analysis Tool (FAT).

In addition to the current tools which principally rely on data from roadway detectors, new datasets are being developed utilising information from the tracking of mobile devices or from the tracking of vehicles equipped with global positioning systems (GPS).

Accumulation of monitored data

The accumulation of real-time data to subsequently serve as historical data is also an important task of the monitoring mission. The use of historical data so gathered can include:

- comparison with real-time data to detect incidents on the network
- before/after study of operations and control functions
- informing ITS-unrelated programs of network improvement such as geometric improvement and pavement rehabilitation.

3.4.2 Detection Technologies and Telecommunication

Monitoring tools and technologies (or some alternative) are well established and new methods are developing rapidly with advancement of information technology. Components include detection methods, telecommunications and the operations centre. The first two are described in this section, while the operations centre is discussed in Section 4. For more details on detection technologies, refer to the Federal Highway Administration *Traffic Detector Handbook* (Klein 2006; Klein et al. 2006).

Detection technologies

A number of technologies are available for traffic monitoring, some of which may also be used for traffic control and incident detection. Some of these technologies have not been used or have only limited applications in Australia. The technologies include those in Table 3.5. The selection of the most appropriate approach depends on fitness for purpose to match needs and available resources. The key considerations are:

- detection speed
- accuracy
- cost
- reliability.

Table 3.5: Detection technologies

Detection technology	Description
Inductive loop detectors	Inductive loops embedded in the pavement to detect the presence or passage of a vehicle. The most common detector used.
Magnetometers	Small cylinders containing sensors embedded in the pavement measure traffic volume and vehicle occupancy.
Microwave radar, infrared, ultrasonic detection (non-intrusive detectors)	Mounted on a structure above or adjacent to the roadway.
Video image detection	Processes images from camera. In sensitive to light conditions.
Probe vehicles	Electronic toll tags have been installed in an increasing proportion of the vehicle fleet. Provides an opportunity to use probe vehicles as sensors to measure speeds and travel times.
Automatic number plate recognition	Can be used to measure speeds and travel times and origin-destination.
Mobile device location	Similar in concept to vehicle probes, but using triangulation to monitor vehicle travel speeds. Bluetooth monitoring technology provides another method of using mobile devices to monitor traffic.
Bluetooth readers	Readers capture the Media Access Control (MAC) address from Bluetooth-enabled devices in vehicles, which is used to estimate travel times and route choices.
GPS tracking	GPS-equipped devices on-board vehicles, such as on busses and trucks.

Table 3.6 identifies different detection methods that may be applied to network monitoring. Detection methods may be either:

- detectors, including detection technologies appropriate to a function (e.g. inductive loop, magnetometer, microwave radar, infra-red, ultrasonic or video detection)
- 'non-technological' methods, which have typically been used for particular functions in network operations projects throughout the world.

Table 3.6: Detection methods

Functions	Detection devices
Monitoring traffic • overall network • traffic nodes and routes.	• Detectors, probe vehicles, patrol reports, aerial surveillance. • Detectors, closed-circuit TV.
Incident management • incident detection/clearance.	• Detectors, probe vehicles, mobile/roadside phones, closed-circuit TV.
Driver information • on-trip/pre-trip information.	• Detectors, probe vehicles, patrol reports, closed-circuit TV.
Traffic control • speed/lane control • intersection/network control.	• Detectors, probe vehicles, patrol reports, closed-circuit TV. • Traffic signal information.
Demand control • ramp metering • vehicle control • toll collection.	• Mainline detectors, entry ramp detectors. • Vehicle weighing and height detectors. • Automatic vehicle identification, video image processing.

Source: Adapted from World Road Association (2003).

Some of the strengths and weaknesses of non-technological detection that should be considered are summarised in Table 3.7.

Table 3.7: Strengths and weaknesses of non-technological detection methods

Detection method	Description	Strengths and weaknesses
Patrol vehicles	In addition to patrol cars, may include other vehicles from various authorities that provide information regarding traffic and road conditions.	Traditionally has always been an important detection method. Information is provided by experts thereby greatly increasing the reliability of information from these vehicles.
Aerial traffic surveillance	Surveillance of traffic conditions from fixed plane aircraft or helicopters.	Can be provided by the road agencies, or media providing traffic information. Can provide a good, overall appreciation of traffic conditions over a large area.
Mobile phone calls from road users	A high percentage of vehicle owners make use of mobile phones. Incidents in both urban and rural areas are reported by this method.	A very convenient method. Suffers from the problem of inaccurate information and prank information. Can also sometimes suffer from an extremely high volume of calls for the same incident.
Roadside phones	Provision of roadside phones connected to an emergency response centre enables road users to report incidents.	Mobile phone use is becoming much more popular, limiting need for roadside phones. Mobile phone coverage may not be available in some locations or road environments.

Source: Adapted from World Road Association (2003).

Telecommunications

The major classes of information to be transferred comprise:

- monitored data from the field
- operational commands from the operations centre
- mechanical status information of field devices.

The cost of a telecommunications system can be a significant portion of the overall monitoring system cost. Consequently, telecommunications systems should be carefully selected with the following requirements taken into account:

- types of information to be transferred (data, video, voice information, etc.)
- volume of information (number of field devices, operation commands, etc.)
- communication partners (field devices, agencies, news media, service providers, etc.)
- extent of field data processing
- data format for communication.

Transmitting video information generally requires greater bandwidth. Use of standardised common data formats and telecommunications protocols may reduce telecommunications system costs, facilitate liaison between agencies and aid the future expansion of monitoring systems.

3.5 Maintaining Road Serviceability and Safety

Maintaining road serviceability covers, in the event of a disturbance, all field operations designed to maintain or restore conditions of road use that are as close as possible to the normal situation. In order to maintain or improve road serviceability and safety, pro-active and re-active measures can be applied. Pro-active measures focus on the quick detection and verification of incidents and unsafe road conditions, fast response and clearance, and implementing pre-prepared strategies to restore normal operations. Traveller information is also an important preventive measure. Timely warning of unsafe road conditions and congestion reduces the occurrence of crashes and unnecessary delays.

Incident management strategies have been found to reduce freeway congestion by up to 30%, secondary crashes by 80%, travel times by 20% and incident duration by 50% (World Road Association 2003). The early detection of incidents and impassable/unsafe road conditions and rapid response and clearance thereof will improve road serviceability and safety and thereby decrease congestion.

Maintenance, rehabilitation and upgrading works, as well as planned special events, must also be regarded as incidents that will have a major effect on traffic conditions if not planned properly. Major weather events can also adversely affect traffic conditions, so technology to detect and track these events, and strategies to respond to them, are also important.

Table 3.8 provides a synopsis of objectives, tools, equipment and outcomes for maintaining road serviceability and safety, and lists some considerations. Key elements are discussed in more detail in the ensuing sections.

Table 3.8: Maintaining road serviceability and safety – summary

Element	Objectives	Equipment	Tools	Outcomes	Considerations
Maintenance, rehabilitation, upgrading works notification(1)	To maintain, restore or improve road conditions to better accommodate traffic.	Standard construction plant and equipment, manual labour.	Planning and scheduling tools.	Better roads. Better trip choices arising from notification.	Requires careful planning: • requires good prior notice • roadworks should not be conducted in peak periods unless urgent • signs and safety are essential.
Road condition warning	To warn the user about road conditions such as icy roads and incidents.	CCTV, inductive loops and other sensors, variable message signs, communications networks.	Information processing.	Reduced crashes. Better trip choices.	Theft of equipment can be a major problem. Vandalism.
Control centre	To observe and respond to various incidents and events.	Various	Various	Better response. Better trip choices.	Effective but requires coordination between parties.

1 *This is not a traffic management issue per se, but is included here for completeness in the context of road network operations as opposed to traffic operations.*

Source: Adapted from World Road Association (2003).

3.5.1 Emergency Response Operations

Emergency response operations include breakdown services, clearance operations and emergency call-out. They may also include provision of warning information for road users.

In case of an incident, the objective is to facilitate quick action by the appropriate emergency services (police, fire brigade, medical services) and/or the breakdown services. The incident area must then be protected and upstream motorists warned as quickly as possible. This may require the traffic incident to be isolated by guidance markings, and the traffic flow to be restored after clearing the obstacles (such as an overturned truck, fallen rocks, etc.) and cleaning up the road.

The prime performance measure is the response time: the interval between the time the management service learns of an incident and the time the response actually begins or the relevant users are informed.

Emergency response operations further require standby of operational teams that can be mobilised within a time period conditional on the level of service sought by the operator.

3.5.2 Weather Related Operations

Weather related operations concern actions connected with the onset of extreme weather conditions. These conditions may include heavy rain, flooding, high wind and winter conditions such as black ice (where salt spreading may be applicable) and snowfalls (requiring snow clearing). Weather related operations also include means of informing motorists and providing advice and assistance.

3.5.3 Organisation of Planned Actions

Organisation of planned actions involves traffic planning for roadworks, organising worksites, the control of the movement of escorted over-dimensional/over-mass vehicles or convoys and the planning and monitoring of special events.

The objective is to limit inconvenience to road users by choosing the least constraining periods and techniques and through information given prior to the anticipated inconvenience.

Successful implementation requires careful planning (prior study, checking, coordination) of operations, may require teamwork by several operators (such as contractors, road administrations, public operators and private road operators) and the implementation of appropriate transport and traffic management plans for the site or event.

3.5.4 Methods

Maintenance, rehabilitation and upgrading works notification

Roadworks may contribute to traffic congestion if not carefully planned and designed. Alternative construction methods and working hours (off-peak, night-time) can improve road serviceability and safety. Re-routing of traffic by means of pre-trip and en route information regarding roadworks may aid in reducing congestion in these areas. Planned special events may also cause significant traffic congestion if not planned properly, taking into consideration the extra travel demand created by the event and the impact of reductions in capacity (e.g. street closures) on the roadway network.

As the inherent safety of the road infrastructure is invariably compromised during roadworks and special events, speed management (generally comprising reduced speed limits and / or physical devices) must be considered in order to offset the increase in crash risk to ensure safe speeds for road users and anyone working near traffic. Effective means of communicating with road users through both pre-trip and on-road information and direction can affect trip choices and behaviours that will support the safe road users Safe System pillar.

Weather and road condition warning

Driving can be heavily affected by weather conditions, such as snow, heavy rain, storms, fog and icy roads. It is therefore important to inform drivers of weather conditions in advance, so that they can change their travel plans, or at least proceed with due caution. Warnings on conditions that may be hazardous, such as icy roads, are especially helpful. Where possible, condition warnings should be supported by lower speed limits to encourage safe speeds. Installation of variable speed limit (VSL) signs should be considered at locations where adverse conditions are regularly experienced, particularly if drivers may not be aware of the increased risk (e.g. black ice). Various adverse weather and road condition warning systems can be used to serve this purpose. Australian and New Zealand examples include:

- fog and ice warning systems in New South Wales
- high wind warning systems in Victoria (including VSL signs)
- ITS-based flood notification systems in Queensland
- avalanche warning system, Milford, New Zealand
- lahar (volcanic mud flow) warning system, Central Plateau, New Zealand.

Reactive measures

Safety cannot be achieved by preventive measures alone. It is important to constantly monitor conditions on and off the road and the traffic to effectively react to situations. This is often achieved through an integrated traffic management centre which, in addition to its traffic management role, can provide a focus for quick response deployment of resources to attend to reported road condition problems. Where the capability exists, the speed limit should be reduced to compensate for the increase in crash risk during critical incidents e.g. using VSL signs on managed motorways.

For incidents involving injured road users or road workers, rapid response by emergency services can limit the severity of injuries and potentially save lives. Post-crash response is often recognised as the fifth pillar of the Safe System.

Technologies

The main technologies and tools used in maintaining road serviceability and safety are, from a traffic operations perspective, those also used in:

- network monitoring (i.e. CCTV, inductive loop detectors and other sensors)
- travel aid and user information services (i.e. variable message signs, VSL signs etc.).

Traffic incident detection forms part of most integrated intelligent transportation systems, although automated incident detection systems are to some extent being overtaken by mobile phone reporting from road users. Automated incident detection is most commonly found in urban areas where traffic congestion during peak hour periods is experienced.

3.6 Traffic Control

Traffic control covers all measures aimed at distributing and controlling traffic flows in time and space, in order to avoid the onset of disturbances or to reduce their impacts, while maintaining a high level of safety. Traffic management tasks can be preventive or remedial. Providing traffic control is one of the major roles for the network operator. Major services and systems supporting traffic control include, for freeways and motorways, ramp metering, lane use management and speed control, and for arterial roads, adaptive traffic signal control. Reversible lane (tidal flow) control and route guidance systems embrace both types of road.

Choices and uses of traffic control services and system have a significant impact on how the road network will align with the Safe System. In general, alignment is positive. For example, systems that are aimed at optimising the use of motorway capacity (e.g. ramp metering) and to detect and manage incidents contribute to safe roads and safe speeds. Information provided to road users via different media can contribute to safe road users by minimising driver stress (which can lead to risky behaviour and driver error) and promoting the use of safer routes. However, it is vital that information is delivered in a manner that is timely, not distracting to drivers and easy to comprehend i.e. not complex or ambiguous.

Table 3.9 summarises the objectives, equipment, tools and lessons learned on traffic control.

Table 3.9: Traffic control – summary

Control type	Objectives	Equipment	Tools	Effectiveness	Considerations
Ramp metering	Optimise the use of motorway capacity through better merging of entering traffic.	Traffic signals and control equipment at entry ramps. Centralised or on-site computation facilities. Traffic data collection stations. VMS.	Real-time local control algorithms (for example, demand/capacity algorithm). Coordinated centralised control algorithms.	Speed increase on the motorway. Decrease in fuel consumption and air pollution. Increased safety on the mainline.	Very effective technique for motorway operation. Queue spillback from entry ramps needs to be managed to minimise disruption to through arterial movements. Public acceptance and reinforcement (for people to stop at the ramp signal). Risk of rear-end crashes at entry ramps.
Speed control	Optimise the use of motorway capacity through speed smoothing (shift of traffic breakdown point, decrease of incident frequency).	Traffic data collection stations. VMS. Local or centralised computation facilities.	Special algorithms for the calculation of displayed speeds.	Increase of effective motorway capacity. Decrease of rear-end crashes.	Speed control may not increase capacity at bottleneck. Speed control allows an increase of effective capacity (less rear-end collisions). Speed control entails better safety conditions (drivers are alerted when approaching a queue).
Lane use management	Optimise the use of road capacity through dynamic lane use assignment. May include: lane opening/closure dynamic creation of bus/HOV lane/truck lanes dynamic operation of reversible lanes.	Traffic data collection stations. VMS. Local or centralised computation facilities. Video surveillance system for reversible lanes.	Decision support tools for lane allocation. Manual action remotely launched. Verification by video cameras.	Reduction of recurrent congestion. Better safety conditions for drivers and operating emergency personnel (crashes, roadwork).	Deployment of equipment for lane reversal under traffic flowing conditions is critical but feasible, especially with the help of video monitoring.

Control type	Objectives	Equipment	Tools	Effectiveness	Considerations
Adaptive traffic signal control	Optimise the use of urban street network capacity. Provide specific services to fleets (public transport, emergency vehicles).	Traffic data collection stations. Sensors (inductive loop, video) for traffic volume and saturation measurements at junctions. Traffic signals and controllers. Centralised computation facilities. Sensors for the detection of special vehicles.	Traffic-responsive algorithms for real-time calculation of traffic signal timings under saturation-free conditions. Special heuristic procedure for saturated conditions. Algorithms taking into account new parameters measured.	Reduction of total travel time spent. Increase in the average travel speed of individual vehicles and of public transport. Reduction in energy consumption and air pollution.	The performance of ATC systems is likely to deteriorate if not kept properly tuned. Urban traffic control techniques are near to reaching their maximum potential effectiveness. Next step is demand management strategies in order to decrease the individual vehicle travel (modal shift, time departure shift) by means such as congestion pricing, parking pricing, road use restriction.
Route guidance	Optimise the use of grid road networks through influencing route choice at decision points by means of variable message signs: directional VMS route advice.	Traffic data collection stations. VMS upstream of choice points on the network.	Algorithms for predicted travel time calculation and/or strategy simulation/ generation.	Very effective in case of major imbalance between competing routes.	Re-routing traffic needs prediction in order to avoid over-diversion phenomena. Dynamic control needs strategies to be real-time tailored instead of being real-time chosen from among pre-determined strategies.

Source: Adapted from World Road Association (2003).

3.6.1 Preventive Action

Preventive actions aim to adjust road travel demand in time and/or space. They can consist of:

- routine operation of systems to maintain optimum traffic conditions (e.g. traffic adaptive control systems have the ability to delay the onset of congestion)
- measures to warn users of foreseeable traffic difficulties (e.g. those due to holiday traffic, weather, natural conditions or planned events) enabling road users the opportunity to change their time of travel, modify their route or abandon their trip.

Preventive action requires:

- a capacity (e.g. systems) to control traffic in such a way as to maintain optimal conditions
- a capacity to predict traffic disturbances (whether sporadic, foreseeable or recurrent)
- response or contingency plans that can be used in the event of foreseen difficulties
- dissemination of information regarding preventive actions to the users.

3.6.2 Remedial or Corrective Action

Remedial or corrective action is required to limit the extent or impact of disturbances occurring regularly on major roads, through measures to limit access and divert traffic onto less congested routes.

Corrective action requires:

- **traffic management plans** drawn up in conjunction with police and road operators which, for each of the foreseeable types of disturbance, define the action strategy and lay down the rules for initiating measures to be implemented by the services concerned
- the use of a **permanent or ad hoc detection and monitoring system** on traffic flow conditions: data collection, centralisation and processing with a view to diagnosing the situation and how it may develop, and initiating traffic management measures
- the deployment of **operational action teams** for guidance marking and closure of access in the absence of automatic systems, or when field monitoring is required

- **real-time road user information systems** on disturbances, instructions or recommended routes
- the activation of equipment for network information/management, such as information systems using variable message signs.

3.6.3 Implementation Issues

ITS infrastructure

ITS measures in the area of traffic control require basic infrastructure the type and extent of which will depend on the system to be implemented. Aside from communications infrastructure, various items of 'soft' infrastructure may be required, for example:

- data sources and data management infrastructure:
  - these may be common to network monitoring functions (Section 3.4)
- digital map and a geographical information system (GIS) to aid traffic planning and assessment:
  - as the benefit of such a system is not limited to traffic functions alone, there may be room for cooperation with others within, and perhaps outside, the organisation to develop and adopt a common GIS platform.

ITS infrastructure also requires that issues of emergency management and system disaster recovery also be addressed. Section 4 outlines the needs and considerations for traffic management centres, but these are also relevant to ITS infrastructure located in the field.

Staff

The operation and support of ITS requires staffing with higher order skill sets than has previously been the case. Recruitment and retention of people with the required skills is a challenge.

Maintenance of system configuration

Many ITS require substantial effort in configuration to operate optimally, and regular review of the configuration data is often required to ensure the system continues to operate optimally in the face of a changing traffic environment. It is rarely possible to 'set and forget' and expect continued optimal operation.

Adaptive traffic systems (ATC) are a case in point. Although ATC systems can provide substantial benefits compared to fixed-time systems, the performance of ATC systems is likely to deteriorate if not kept properly tuned (Austroads 2007b). Research conducted by Gartner et al. (1995) exploring this issue is discussed in Commentary 2.

[see Commentary 2]

Future of ITS in traffic control

Further improvements, when control systems have found their limits and where new roadway infrastructure building becomes unfeasible, will probably come from demand management and restrictions to the free use of individual vehicles, such as electronic road pricing.

3.7 Travel Aid and User Information

Travel aid covers all measures to disseminate predictive or current information on traffic conditions and to improve general conditions of network use. Effective communication and transfer of information will support the Safe System safe road users pillar.

Travel aid measures are not directly aimed at modifying traffic flows. However, when used for information purposes, they must be closely coordinated with traffic management measures as they may induce users to change their travel time or route. They may also induce users to change their travel mode. In this context, they may be integrated in broader strategies related to demand management.

The common objective of all traveller information services is to provide high quality, real-time, detailed information on transportation system operational conditions, including weather, so that travellers can make informed decisions regarding whether to make a trip, when to make it, what mode to take, and what route to take. Traveller information should be available both before a traveller begins a trip, as well as while the trips are underway, so that adjustments can be made to reflect changing operational conditions. Traveller information can be provided in a number of ways. These are discussed below. Further guidance on measures and systems in use in Australia and New Zealand particularly directed to road users, can be found in Section 7.5.

There have been few comprehensive evaluations that attempt to numerically quantify the benefits of traveller information. However, users of traveller information services generally agree that availability of high quality, real-time traveller information saves time for users, helps them to avoid congested locations and incidents, and reduces uncertainty and stress associated with travel.

Delivery of information during travel requires careful consideration to ensure that it enhances road user safety. Complex messages and poor interfaces are likely to distract drivers from critical driving tasks and, where driver action is required, increase reaction and response times. There is an increasing number of driver support systems being introduced both on the road network and within vehicles and it is critical that issues of integration and interoperability are given due consideration. Further information on these matters is presented in Section 3.10.

3.7.1 Predictive Information

Predictive information concerns general traffic condition forecasts and the main planned incidents or other anticipated disturbances and may be on a weekly, daily or even hourly basis. Implementation of a system to manage and disseminate predictive information requires:

- real-time **centralisation of information** on the network situation (traffic, weather) and on scheduled actions (roadwork, events)
- **transmission of regular information bulletins** through national or local media (radio, newspapers, television), or specific road information facilities (kiosk, telephone enquiry service, internet).

3.7.2 Real-time Information

Real-time information concerns traffic conditions and unanticipated disturbances affecting motorists on a given route. It requires:

- a permanent system to detect and monitor traffic flow conditions
- real-time information systems by variable message signs installed along the route.

It also includes provision of information to service providers of traffic information services for navigation and guidance systems and other customised traffic alert services.

3.7.3 Miscellaneous Equipment

Travel aid and user information services can also be considered to include conventional facilities designed to improve the level of service to the road user, such as static direction and other signs, and rest areas.

3.7.4 Methods

Internet

The internet has become a very popular method of conveying pre-trip traveller information. All Australian state and territory jurisdictions and the New Zealand national agency support a traffic and/or road condition web site. Some systems operated by the private sector offer subscribers the option of receiving alerts by e-mail, or other electronic methods regarding major incidents or conditions on specific routes.

Commercial broadcast media

Commercial broadcast media, including radio and television, are popular methods of dissemination of pre-trip information. The underlying information is often provided by road agencies to commercial providers who may also have their own information sources.

In some major tunnels, systems are provided to enable operators to override broadcast radio on all commonly used frequencies with warning messages regarding conditions in the tunnel.

VMS

Variable message signs (VMS) are used to disseminate en route traveller information in virtually all locations where electronic traffic monitoring also exists. These signs are typically placed in advance of key bottlenecks or decision points and can display fairly detailed information on location and extent of congestion, travel times, alternative routes and downstream weather conditions.

Highway advisory radio

Highway advisory radio, usually based on a low-powered ‘narrow-cast’ FM radio transmission has been used, particularly in the USA and Europe, to provide travel and traffic information specific to the localised area around the transmitter. Its use in Australia and New Zealand has been more oriented to providing tourist information. Its use in Europe appears to be declining with the popularity of RDS-TMC applications (Radio Data System – Traffic Message Channel), which are now widespread.

En route via in-vehicle navigation systems

En route information provided through in-vehicle navigation systems is based on FM radio communications providing information for display on the in-vehicle navigation system. Examples include RDS-TMC based systems which enjoy widespread use in Western Europe, and VICS (Vehicle Information and Communication System) in Japan which enjoys a high market penetration of in-vehicle navigation systems. Dissemination of detailed en route information is accomplished through transmission from beacons or FM sub-carrier broadcasts to the in-vehicle device. In Australia, navigation systems currently available have the capability to display en route information received via FM transmission.

Messaging services

Pre-trip and en route information provided through messaging subscription services (e.g. mobile phone) is being applied.

3.7.5 Implementation Issues

High quality traveller information services must be driven by high quality data on transportation system conditions and performance. Effectively fusing data into useful information from various input sources remains a significant challenge that is critical to overcome if traveller information services are to be effective. For systems that automatically post or otherwise provide traveller information based on input from traffic monitoring systems, data reliability is a critical issue. Effective automatic means of checking or filtering raw data are required to ensure that erroneous or misleading information is not posted.

In order to be of maximum use to travellers, traveller information needs to be multi-modal (road and transit), and regional (crossing jurisdictional boundaries) in scope and include information about motorways and urban streets, as well as location and availability of parking. Travellers are interested in receiving end-to-end trip information in a single query. Future enhancements for end-to-end travel may include linking to intercity travel providers, such as rail and air lines, to provide complete travel and routing information. However, not all systems can deliver all items required for end-to-end trip information. Roadside signs, for example, are limited in the amount of information they can provide. The holistic approach described above is therefore a goal more for non-roadside systems.

It is important to maintain the accuracy and currency of the information provided. VMS information, for example, will not be trusted if the messages displayed lack reliability, i.e. currency, accuracy and relevance. This will defeat the whole purpose of the system. To ensure accuracy, one issue is the interconnections between the various centres, which are separate either in terms of the services that they provide or their locations. In order to provide a seamless service to the users, the seamless integration between various centres requires a standard for data sharing, and cooperation between the various players.

Users are interested not only in real-time network conditions information, but also in predicted conditions (i.e. 'a key junction is currently uncongested, but if the current trend continues, what will conditions be when I reach the location in 30 minutes?'). This appears to be the next needed innovation in traveller information services and examples of this service have already been piloted.

3.8 Demand Management

Demand management in general is discussed in Part 4 of the Guide to Traffic Management (Austroads 2016a). This section focuses on demand management only in relation to traffic operations.

Demand management in this context covers all operational measures that aim to limit the consequences of a decreasing level of service on a route. This is carried out through actions such as improving traffic distribution through time or encouraging users to modal transfer.

Operational tasks related to demand management should be integrated in a multimodal mobility policy with the road being part of it. They are closely related to, and complement, some traffic management actions, for example those related to assisting road-based public transport.

From a traffic operations perspective, the main contribution to demand management is through the provision of information to road users that could potentially cause a change of mode, a change of time of travel or a change of route. Information of this type is provided, via the media described in Section 3.7.4, in most cities. This is a fairly simple measure that can be implemented for a relatively low cost. It is not restrictive, and it leaves the decision to the users.

3.8.1 Modal Transfer

The objective of modal transfer is to create conditions for increased use of public transport, in order to limit degradation to a roadway's level of service. This reduction could be due to a temporary capacity decrease (e.g. due to roadwork) or to congestion on the road itself or within the served areas.

One possible operational measure is to provide users with real-time information regarding public transport services and related transfer points (e.g. park-and-ride, railway stations or train frequencies). This may be facilitated through variable message signs or in-vehicle information devices (e.g. conventional broadcasting, radio data system traffic message channel RDS-TMC or route guidance systems). These actions complement measures related to travel aid and more conventional information to road users.

3.8.2 Road Pricing

Road pricing is generally defined as a mechanism that charges road users for the use of a certain road or section of a road network. In this definition, road pricing does not include parking levies, fuel and vehicle taxes. Austroads (2011) reviewed the various types of road pricing schemes and their impacts, as well as, electronic payment techniques. Road pricing can impact route choice, time of departure choice, mode choice and the frequency of discretionary trips.

3.9 Enforcement

Enforcement activities and systems associated with traffic operations are for the most part aimed at improving road safety. However, the effectiveness of a number of non-safety related traffic operations measures (bus and other priority lanes, HOV lanes, clearways, ramp metering, ETC, congestion charging) is often dependent on effective enforcement measures. While this is not usually a road agency function, it is a critical element affecting the success of some traffic operations. From a credibility point of view it is important that such enforcement be seen as supporting traffic operations and not merely being used for revenue-raising.

The main enforcement activities and systems associated with traffic operations in Australia and New Zealand are listed in Table 3.10.

Table 3.10: Enforcement – summary

Enforcement activity	Objectives	Method	Requirements	Outcomes	Considerations
Speed camera	To automatically detect offences and consequently deter them.	Speed detectors and cameras, either fixed or mobile: • may be deployed as part of a freeway/motorway management system • may operate on a point-to-point basis.	Accuracy: • outputs that can be substantiated in court.	Reduce crashes. Improved compliance may assist smoother freeway/motorway flow and marginal capacity increase.	Public support and credibility requires location selection in accordance with accepted criteria. Coordination between parties, especially with enforcing agency. Privacy issues.
Red light camera	To enforce compliance with traffic signals.	Detectors and cameras at traffic signals and ramp meters: • may be combined with fixed speed cameras.	Accuracy: • outputs that can be substantiated in court.	Reduce crashes.	Coordination between parties, especially with enforcing agency. Privacy issues.
Bus lane camera	To support the effectiveness of bus lane operation by deterring non-bus users.	Detectors: • may be loop-based providing bus profile recognition • may be video-based vehicle recognition or number plate recognition.	Accuracy: • outputs that can be substantiated in court.	Ensures facility is available for intended purpose. More efficient bus operation.	Careful location to maximise length over which deterrence is effective. Privacy issues.
HOV lane enforcement (including T2 and T3 transit lanes)	To support the effectiveness of HOV lane operation by deterring non-eligible users.	Manual: • at the time of writing no automated method of detecting vehicle occupancy with sufficient accuracy exists • developments in automatic enforcement have trialled tools that count the number of occupants in a vehicle through the use of infrared technology or require HOV lane users to equip vehicles with toll tag transponders (Lobo 2005, Wikander & Goodin 2006) • to date, technological challenges and other issues have limited automated technologies from supplementing or replacing manual enforcement.	Suitable road space to allow enforcement activities without impeding operation of the HOV lane. Dedicated enforcement bays may be required.	Ensures facility is available for intended purpose.	Availability or feasibility of providing areas for enforcement activities.
Parking	To support effective operation of clearways and HOV lanes.	Manual: • parking fines • tow-away schemes.	Appropriate arrangements to administer fines and towing fees. Systems and procedures to support owners' recovery of towed vehicles.	Ensures facility is available for intended purpose. Maximum available capacity of arterial roads.	Effective surveillance to facilitate detection of vehicles parked on clearways or HOV lanes.

3.10 Integration and Interoperability

So far, individual technologies have been discussed. However, concentrating solely on the issues associated with individual technologies can be misleading in the long run. The sum of individually optimal solutions may not lead to an overall optimal solution. Since there are numerous possible technological solutions for any class of network operational issue, conflicts between various services is a real risk. Also, with the rapid evolution of technology and services, new and better applications are always on the horizon. Fine-tuning to a state-of-the-art single application at the moment may sacrifice the ability for the system to evolve in the future. These issues can be summarised as integration and interoperability issues.

3.10.1 Integration

The need for integration

The need for integration is apparent when considering problems that may occur by pursuing single-function systems.

Various systems may rely on similar sets of data

Various traffic information services rely on similar sets of data. Traffic volume data, accident data, and weather data may all be used in various ways by various services. It would be impractical and probably impossible for every service to create its own traffic data from scratch. Usually, it would be much more efficient to separate the data collection and create a platform or protocol for shared use, allowing for sharing between various systems. Data sharing that allows for integration allows for higher flexibility and variety of services.

Fragmentation of services

It is often problematic for users to deal with separate systems or services whenever they move to a new area. While network operation is aimed to facilitate mobility, the fragmentation of services might even hinder such mobility. It is much more convenient from a user viewpoint to be able to use the same system and services seamlessly among various geographical areas and jurisdictions. A system designed with such horizontal integration in mind greatly improves the utility of a service.

Issues of human machine interface (HMI)

Many services that enhance network operation require user interaction within the vehicle, often while driving. Lack of consideration for other systems would lead to a random assortment of proprietary displays and input devices, especially within the vehicle. The risk of driver distraction is very real, and as the number of interfaces within the vehicle increases, the risk of misuse and confusion would rise exponentially. Integrating various services could also integrate these interfaces into a more usable and understandable system.

Development cost

Many services require similar components, such as communication channels, or a common geographical database, or payment systems. If all services were developed separately, these similar components would have to be developed, tested and deployed independently, which is wasteful and time consuming.

Interference between systems

Interference between systems is another important issue. Integrated systems, if properly tested and fielded, would decrease such risk by assuring that the integrated services work properly together.

Methods of integration

There are several possible approaches to integration:

- comprehensive system
- integration of existing systems
- standardisation
- system architecture.

Table 3.11 summarises the issues associated with each. A more detailed discussion can be found in World Road Association (2003).

Table 3.11: Integration issues – summary

Integration method	Objectives	Method	Requirement	Outcomes	Issues
Comprehensive system design	By designing everything together, avoid redundancy and the issues of interoperability.	Overall design.	Good understanding of the overall needs. Good coordination between parties involved.	Provides uniformity of services, i.e. avoids redundancy.	Time consuming to design a huge system. Risk of low maintainability, risk of low upgradeability and possibly difficult to adjust to new conditions (these issues could be resolved through good planning and modular approach).
Integration of existing systems	Provide wider coverage by connecting similar systems in different areas.	Create an interface system.	Good coordination between the parties. Certain level of uniformity in the services.	Possible to create a seamless wide area service. Increased utility.	Bad integration may deteriorate the existing services. How to filter the relevant information from the wide area information.
Standardisation	To ensure interoperability between components, services and equipment.	Activities of the standardisation bodies. De facto process of the market.	Agreement between the parties involved.	Provides versatility. Expand markets by allowing for competition.	Very slow process; often difficult to reach agreements. Danger of a standard that no one uses.
System architecture	Ensure the soundness of the overall structure whilst promoting interoperability.	Activities of the standardisation body.	Good cooperation and agreement between the parties involved. Good review process to allow for possibility of expansion.	Create a broad picture. Allow various new innovations that operate on the architecture.	Very slow process; often difficult to reach agreements. Danger of a standard that no one uses. Possible over-complication.

Source: Adapted from World Road Association (2003).

Implementation issues

Integrating various systems is an effective approach to network operations. There are, however, a number of issues that need to be addressed (World Road Association 2003):

- Plan ahead:
  - Achieving integration as a second thought may prove to be extremely difficult. Once a system is in place, replacing it may involve significant financial and institutional resistance. If there is any possibility of integrating various services in the future, it should be included within various considerations from the beginning.
  - In addition, various efforts to bring the players together and reach an agreement require a significant amount of time. Road network operators need to allow time for that negotiation process.
- Short term and long term benefits:
  - An integrated system means that it may be difficult to optimise for a single application or service in the short run. Common and standardised protocols may not be the optimal solution for that particular service. For example, if an electronic toll collection (ETC) system is required only for a single stretch of toll road, it may not make sense to consider a common national system, which would require a more complex system. It should prove beneficial in the long run, but just how long may differ from place to place, and in the short run, it would be easier and cheaper to introduce an off-the-shelf ETC system.
  - The planning horizon for each operator will differ. It should, however, be noted that the decision to (or not to) integrate a system would also be affected by that horizon.
- Existing standards versus new standards:
  - Sometimes it may prove that the existing data formats or communication protocols are not sufficient. Creating a generic and standard protocol or data exchange format, however, is not a trivial task, especially for network operation applications that are often mission critical. By integrating various services into a single communication protocol, for example, the system would have a single point of failure. The protocol needs to be extremely robust, and the testing that is required ensuring robustness will become difficult as the complexity and the importance of that module increases. In some cases, it makes sense to sacrifice the level of the service in order to achieve integration using an existing and proven standard, rather than trying to create an optimal one.

Obviously, many of the issues concerning integration are not purely technical, but institutional. The negotiation between participants, the division of labour between the private and the public sectors, the issue of acceptance, all become extremely important in an operator's decision process.

3.10.2 Interoperability

A definition of interoperability when applied to ITS systems is (World Road Association 2003):

> The ability of ITS systems to provide services to and accept services from other systems and to use the ITS services so exchanged to enable them to operate effectively together. ITS systems are interoperable when the ITS services are seamlessly provided in time and space.

ITS interoperability is particularly relevant to the road user and the road network operator. In Australia the arterial road network is usually operated by state or territory road agencies, although some tolled elements may be operated by private sector operators. Other levels of the road hierarchy are usually operated by local government bodies. In New Zealand the state highway network is operated by the national road agency, while the remainder of the network is operated by the road controlling authority, usually the local authority. In both cases operational responsibility is divided across different road classes and interoperability is therefore a potential issue.

For a service to be interoperable three levels of interoperability must be addressed:

- Technical interoperability is the capability of the technical subsystems to communicate with each other by using standardised interfaces and communication protocols. Typical issues are the physical layers and data layers for radio transmission.
- Procedural interoperability is achieved when common procedures are used by all involved road network operators and by the users. Typical issues are harmonised data dictionaries or common human machine interfaces (HMI).
- Contractual interoperability requires agreements between network operators about issues such as operational procedures, service levels, financial transactions, data security, and enforcement.

Where is interoperability needed?

Interoperability is a particular issue if a system is composed of both fixed and mobile subsystems. For example, on-board units in cars that travel across borders or between jurisdictions must be able to communicate with roadside equipment at different geographic locations. Interoperability is also an issue where the impacts of traffic operations cross the borders of the areas of responsibility of adjacent operators and they need to exchange data, information or control. The priority areas for interoperability are:

- **Traffic management and control**: Cross-jurisdictional traffic management requires the exchange of traffic information among network operators and harmonised procedures for network management (e.g. where do adjacent network operators want to concentrate traffic flow, how to manage major incidents that impact on adjacent network operators).
- **Traffic and traveller information (TTI)**: Data originating from many different sources (roadside traffic sensors, traffic police data, user calls, traffic management centres) that are disseminated to the users by means of different systems (roadside VMS, radio, internet, on-board navigation equipment) must be harmonised in order to avoid providing conflicting information to drivers. For example, there should be convenient means available to the drivers to acquire digital road maps in order to ensure seamless provision of TTI services across borders.
- **Electronic toll collection (ETC)**: Common ETC payment for cross-concession travel requires on-board units that are able to communicate with roadside beacons at toll stations and requires agreements between the toll operators about clearing procedures.
- **Incident and emergency handling**: In emergencies, travellers should be able to call services with their own equipment (mobile phone, on-board emergency system) no matter where they travel, and the emergency services should be able to find the relevant information about the vehicle, the persons and freight carried regardless of the origin of a vehicle. While mobile phone networks and on-board emergency systems are not the responsibility of a road agency, traffic management centres operated by road agencies must be able to accept information flowing from the systems of those who are responsible.

Costs and benefits of interoperability

The disadvantages associated with interoperability are:

- a certain loss of autonomy of the network operator combined with what can be time-consuming procedures for negotiating the procedural and contractual issues
- in some cases, more expensive equipment due to additional functional requirements (e.g. multi-standard roadside equipment or multi-standard on-board units)
- cost of migrating from non-interoperable systems to interoperable systems (e.g. renewal of existing systems that do not comply with new standards).

The benefits of interoperability are:

- more effective management of cross-border traffic operations issues, e.g. incident management
- additional comfort for travellers that can use their ‘home’ equipment and means of payment when travelling in other jurisdictions
- savings to car owners because of avoidance of having to carry more than one on-board unit to carry out the same function
- more competitive bids due to a larger common market when network operators are calling for equipment; multi-sourcing instead of mono-sourcing, e.g. traffic signal controller equipment.

A particular issue for all interoperable systems is non-equipped users, i.e. vehicles that should use a service but do not carry the proper interoperable equipment on board. If the network operators are to ensure they do not discriminate against non-equipped users (such as interstate users of a system implemented in only one state or territory), then solutions must be offered to ensure that a manual procedure is offered for the same function.

How to achieve interoperability?

There are three institutional layers involved in interoperability.

- **Governmental and intergovernmental layer**: Harmonisation of the road traffic regulations and in particular the technical requirements for vehicles and on-board equipment including harmonisation of driver education with respect to the human machine interface (HMI).
- **Architecture and standardisation**: The key to interoperability is standardisation, preferably within a common architectural framework. Only when interfaces are standardised can the different subsystems inter-operate to carry out a particular function. Standards must include test procedures so that equipment can be certified by the operators for inter-operable use. For network operators the following standardisation body is of particular importance: Technical Committee TC 204, Intelligent Transport Systems, of the International Organization for Standardization (ISO).
- **Business to business agreements**: The vehicle manufacturers and the electronics industry have been working together for a long time towards the development of inter-operable systems. However, there are business cases where a strong commercial interest exists for excluding competitors from entering an established system. Road agencies have little role other than encouragement in this layer.

4. Systems and Procedures for Traffic Management Centres

4.1 Overview of Traffic Management Centres

4.1.1 Role

The role of a traffic management centre (variously referred to as transport management, traffic operations or traffic control centre in different jurisdictions) is to act as a focus for the following:

- monitoring the road network
- command of traffic operations on the network
- coordination of incident management and planned and special event management
- control of traffic on the network through the control systems at its disposal
- dissemination of traffic information to the media and service providers.

A traffic management centre, is the focal point for the technologies used in traffic operations, particularly the telecommunications, and surveillance and detection technologies deployed in network monitoring. The systems employed in a modern centre are of two types: those directly supporting system functions and those that are 'enablers' such as communications, video switching, data handling and fault management.

In Australia, road agencies have a traffic operations mandate covering both freeways and surface arterial roads. In this respect, Australia is in a good position to provide an integrated approach to traffic operations. In New Zealand responsibilities for these classes of roads are generally divided between local authorities and the state highway agency but some local agreements are in place to manage coordination.

Nevertheless, toll road operators commonly have their own control centres, which include some traffic operations functions. Further, major tunnels often also have a dedicated control room, facilitating the integration of traffic operations systems with ventilation and communications. In such cases, communications and exchange of data and information between the toll road or tunnel control room and a city's principal traffic management centre is essential.

Centres serving smaller cities may not provide the full range of functions; clearly this will depend on the size of network covered and the traffic activity on it.

Essentially a traffic management centre (TMC) is a service delivery mechanism for road user support services. It is a resource with which to manage use of the road network from one place in real time.

A growing trend is the integration of broader transport operations activities into the functions of the larger TMCs. This arises largely from the growing focus on sustaining efficient public transport operations in the face of increasing general traffic volumes, and on the role of a TMC in providing a focus for special event management. For this reason some TMCs, even though operated by road agencies, also support the full time presence of public transport operations personnel. Commentary 3 discusses this further.

[see Commentary 3]

4.1.2 Scale

The size of a TMC and the range and complexity of the systems it supports will depend on the type and scope of road network that it manages and the intensity of traffic use of the network. TMCs range from:

- large, purpose built centres operating 24 hours every day with staffing levels varied in response to activity levels and peak traffic periods (Figure 4.1)
- for small cities, a small room with work stations for one or two part-time operators (Figure 4.2).

Austroads (2007c) presents, as a series of Exhibits in the report, brief descriptions of the Perth, Melbourne and Sydney TMCs, illustrating the range of systems deployed in larger centres.

Figure 4.1: Transport Management Centre, Sydney

Source: Roads and Maritime (2011).

Figure 4.2: Traffic Management Centre, Cairns

Source: Queensland Department of Main Roads (2009).

4.1.3 Systems

The systems supporting the operation of a TMC are of two types:

- Systems directly related to the centre's functions, including:
  - network monitoring
  - incident management
  - traffic control
  - traffic information.
- Enabling systems, which support the TMC functions, including:
  - communications
  - human/machine interface
  - video control for CCTV network
  - traffic data handling
  - activity scheduling
  - fault management
  - web site management
  - databases of spatial, temporal, event, transport and infrastructure related information
  - GIS applications.

The number and diversity of applications and systems supported highlight the need for an effective system integration strategy in a TMC. One element of such a strategy is a common user interface system for the variety of traffic management applications supported in a TMC. The Traffic Management Interface System (TMIS) deployed in centres in New South Wales and Victoria is an example. TMIS provides a user configurable map-based interface for traffic management software applications, displaying information from these applications such as site status, fault alarms, locations of congestion, CCTV images and incidents.

In larger centres, TMC functions will be seen as mission critical in maintaining efficient traffic flow, and the need for formal disaster recovery plans will be an issue for consideration. Disaster recovery plans may, from a systems point of view, involve consideration of:

- the criticality of the system
- the need for redundancy (at hardware, system, services, functional and facility levels)
- the need for fail-safe operation of systems with a safety dimension
- the option of back-up power supplies:
  - uninterruptible power supplies with stand-by generating capacity for critical systems and facilities
  - battery back-up for low power systems.

Note that these considerations can also apply to equipment in the field.

4.1.4 Procedures

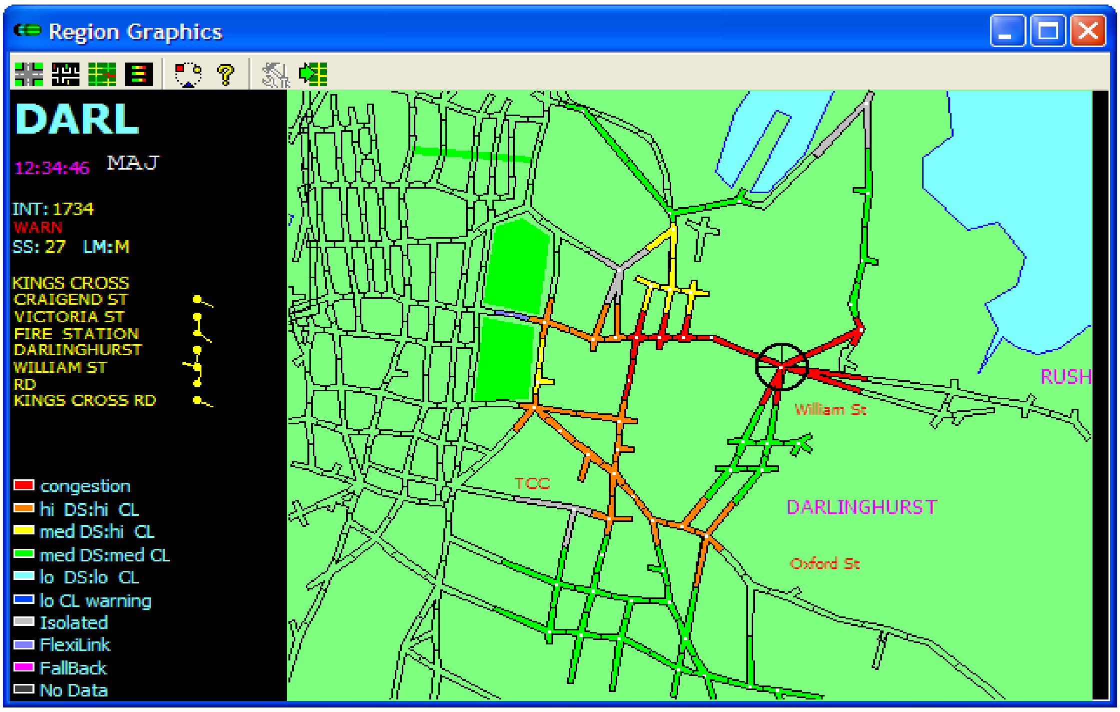
The multiple roles undertaken by a TMC, the around the clock operational nature of the larger ones with consequential reliance on shift staffing and the large range of systems with which staff need to be familiar, require development and maintenance of a comprehensive range of documented procedures covering all activities. This will often be within the framework of a formal quality management system developed in accordance with the principles embodied in AS/NZS ISO 9001.

4.2 Traffic Monitoring

A traffic monitoring capability is at the heart of any TMC. Systems deployed to provide this capability will depend largely on the types of road in the network being monitored.

On surface arterial roads with at-grade intersections controlled by wide area traffic signal systems, traffic signal loop detectors provide a vehicle detection capability enabling some systems (SCATS and STREAMS for example) to identify traffic congestion levels on intersection approaches. Figure 4.3 shows a SCATS display of congestion levels.

Figure 4.3: SCATS display of congestion levels



Source: Roads and Traffic Authority NSW (2000).

Congestion occurring at an unusual time and/or location can indicate the occurrence of an incident. In SCATS the capability to detect this situation is called the Unusual Congestion Monitor.

On motorways or freeways, detectors (in Australia and New Zealand usually loop detectors, but other technologies may be used) provide a first line monitoring capability. For example, automatic incident detection (AID) systems are available to analyse detector data and identify potential incidents. The major issue for TMC operators is the balance between time to detect, detection rate and false alarm rate. An AID system tuned for rapid detection with low probability of 'missing' an incident will also have a high false alarm rate. Means of incident verification are therefore an essential adjunct to detection systems.

Closed circuit television (CCTV) is the most commonly deployed monitoring technology capable of incident verification. CCTV cameras with pan-tilt-zoom capability are normally deployed on major traffic routes, at critical intersections and at hazardous locations such as tunnels. Their role in direct incident detection is limited, but their role in incident verification is essential and they can be useful in monitoring progress during incident investigation and clearance if they happen to be located near the site.

CCTV cameras may be permanently on-line, or dial-up communications may be employed to connect them only when needed. A range of communication technologies with varying bandwidth may be used, with picture quality varying as a result.

4.3 Environmental Monitoring

Environmental conditions affecting traffic flow that can be monitored, and may require intervention under extreme conditions, include weather conditions such as fog, rain, ice and wind, and natural events such as floods and bush fires. Technologies exist for detection of these conditions and for alarm conditions to be notified to the TMC. Examples implemented in Australia include:

- fog detection system with VMS warning/advisory speed signs, F6, New South Wales (Brisbane 1996)
- rain detection system with variable speed limit signs, F3, New South Wales (Wall & de Roos 2006)
- high wind warning system, West Gate Bridge, Victoria
- ITS-based flood notification systems, Queensland (Yung 2001).

CCTV is also a useful tool for monitoring environmental conditions.

4.4 Decision Support

Network monitoring systems must support decision-making. Operator responsibilities are diverse, including monitoring of traffic and environmental information, decision-making on the severity of incidents, selecting and prioritising operational functions and liaison with coordination groups. These processes need to be done quickly in response to the occurrence of incidents. Systems integration in the TMC is therefore important in order to support decision-making processes.

An example of system integration and decision support is the Central Management Computer System (CMCS) in the TMC operated by Transport for NSW. This system integrates:

- traffic data handling
- incident handling
- response handling
- scheduled activities
- setting/monitoring roadside devices
- housekeeping functions
- fault management functions
- human/machine interface (features in addition to those in other discreet functional areas).

It facilitates decision-making. When an incident occurs, the CMCS analyses the affected area and prompts operators to apply pre-defined incident response plans, which include controlling VMS, variable speed limit signs and CCTV cameras.

4.5 Operations Evaluation

Network monitoring systems should support the monitoring and evaluation of other operations functions. The impacts of operational activities are monitored and evaluated to determine further actions. The real-time data flow from SCATS and STREAMS and some freeway and motorway management systems provides traffic condition feedback on actions taken in response to incidents, and CCTV enables incident scenes to be visually monitored if the camera is near the site. A closed loop of information involving monitoring, decision-making and evaluation of resulting impacts is thus maintained.

Developments in probe data, data warehousing, and analytics are opening new opportunities in getting better insights to network performance. One example is the use of Bluetooth readers to monitor unusual congestion (Cox 2014).

5. Systems and Procedures for Maintaining Road Serviceability and Safety

5.1 Incident Management

5.1.1 Introduction

A traffic incident represents an unplanned event creating a temporary reduction in roadway capacity that impedes the normal flow of traffic. Incident induced congestion markedly reduces network system reliability and the quality of service afforded to road users. Emergencies such as extreme weather and natural disasters (including floods and bush fires), and planned events such as roadworks and special events which impact safety and traffic flow, can also be included. An automatic incident detection (AID) system generally aims to detect non-recurrent events (flow breakdowns) after they have occurred. The traffic management centre (TMC) then initiates an incident management plan to resolve the incident. An AID system identifies unusual changes in speed, flow and occupancy.

5.1.2 Overview of Traffic Incident Management

Traffic incident management (TIM) is the process of managing multi-agency, multi-jurisdictional responses to road traffic disruptions. It aims to reduce the duration and impact of incidents, and improve the safety of motorists, crash victims and incident responders. It should reduce the time to detect and verify an incident occurrence, implement the appropriate response; and safely clear the incident, while managing the affected flow until full capacity is restored (Science Applications International Corporation 2010). Efficient and coordinated TIM results in:

- reduction in the duration of traffic incidents, hence reduction in incident-related delay and congestion cost and improvement in the reliability of private, business, public and freight transport
- improvement in the safety of motorists, crash victims and incident responders, by rapid recovery (reducing exposure), thus reducing the risk of secondary incidents occurring and improving the safety of responders
- reduction in energy consumption and improvement in air quality (reduction in vehicle emissions).

5.1.3 Incident Types and Characteristics

It is useful to classify incidents according to their severity and potential duration as this greatly assists in a consistent, appropriate and timely response. A typical classification system that can be used is outlined in Table 5.1.

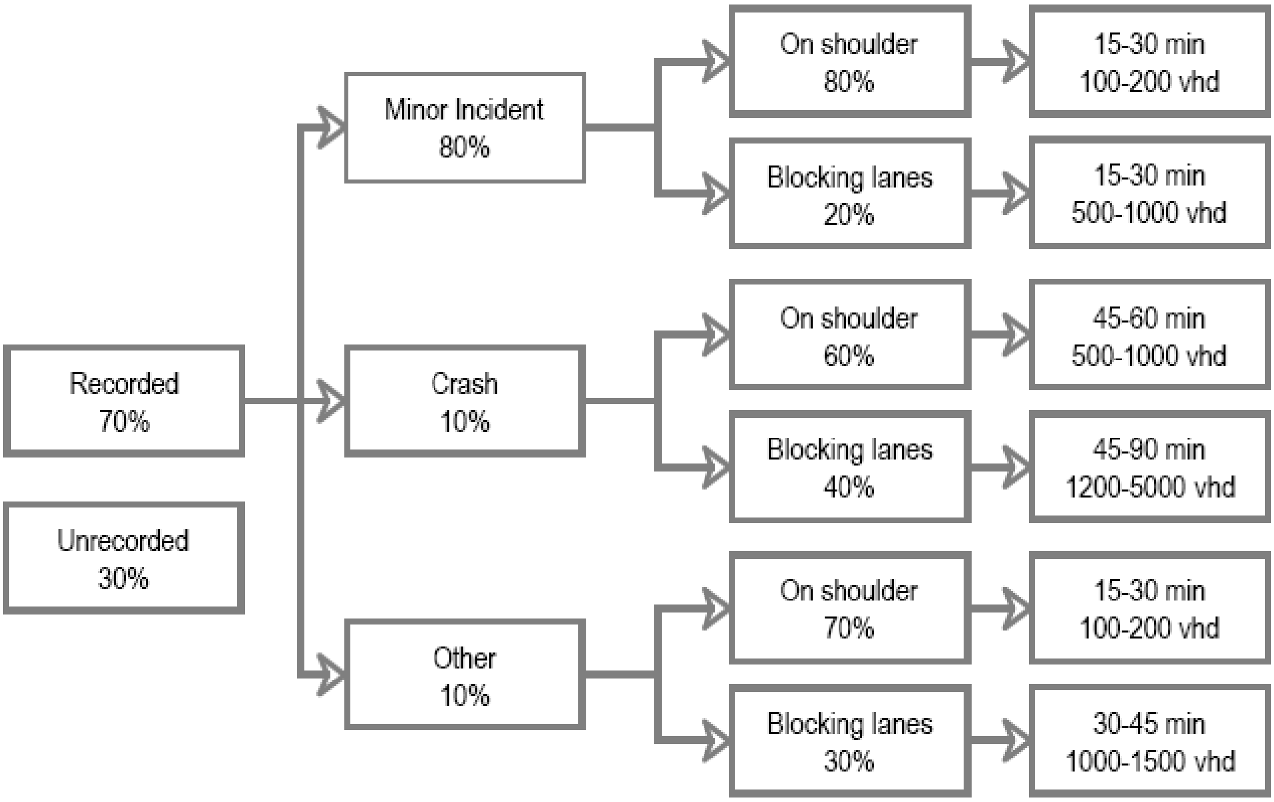
Table 5.1: Typical incident types/classifications

	Level 1	Level 2	Level 3	Level 4	Level 5
Type of incident	Vehicle on shoulder	Vehicle in lane	Minor crash (no injury) Minor debris	Serious crash (injury?) Debris Fire	Major injury crash Hazmat Fire
Estimated duration	Nil	0–30 mins	30–60 mins	1–2 h	> 2 h
Typical response	Traffic Response Unit (TRU)/tow TRUs are roaming on-road services that provide basic breakdown assistance, incident clearance and traffic control	TRU/tow Traffic control	Police Traffic control Tow Clean-up	Police Fire Medical Traffic control Tow Clean-up	Police Fire Medical Hazmat Traffic control Tow Clean-up

Source: Austroads (2007a).

The approximate occurrence pattern of traffic incidents, based on US data, can be seen in Figure 5.1 (Cambridge Systematics 1997).

Figure 5.1: Occurrence of incidents by type



Note: vhd: vehicle-hour delay per day in peak period.
Source: Cambridge Systematics (1997).

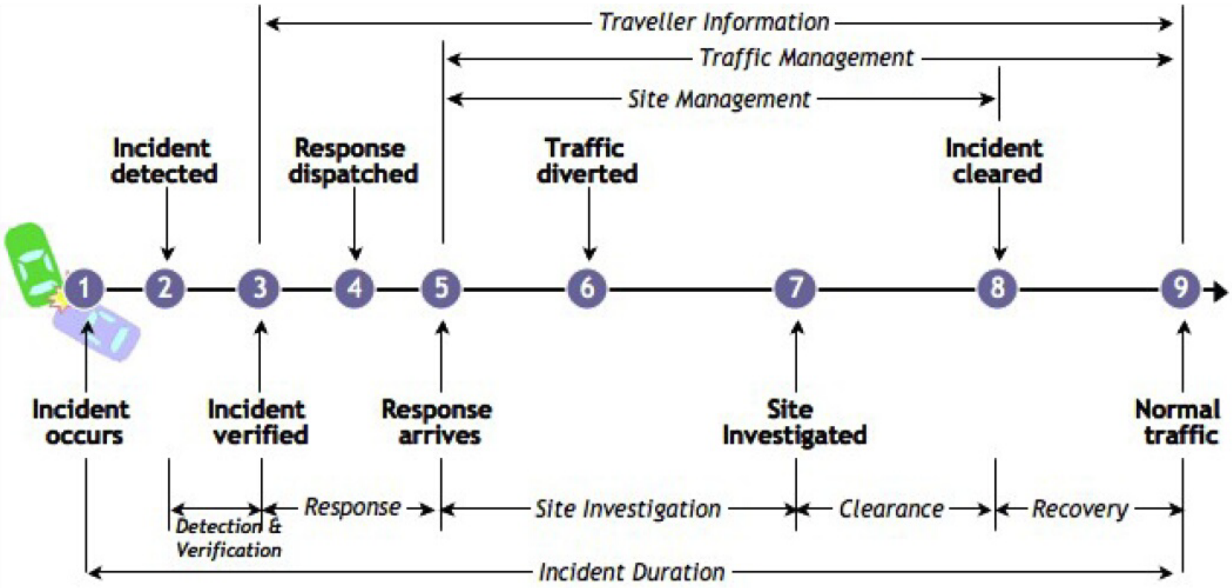
5.1.4 Components of Incident Management

The five major components of traffic incident management are:

- detection and verification
- response
- site management, investigation and clearance
- traffic management
- traveller information.

These components are illustrated on a timeline in Figure 5.2 and discussed in more detail below.

Figure 5.2: Timeline of traffic incident management



Source: Austroads (2007a).

5.1.5 Planning for Traffic Incident Management

Most road traffic agencies respond in some form to incidents that occur, even if no formal incident management programs or policies exist. Planning and formalising incident response plans and programs, and coordinating across multiple agencies and jurisdictions, can result in improved resource efficiency and provide greater benefits to the community by improved safety and reduced congestion. To ensure that planning for traffic incident management is successful, it is important that key stakeholders are identified and involved in the process.

Planning for incident management: recommended practice

- Establish traffic incident management as a key priority in each key responder agency.
- Closely involve key stakeholders in planning for traffic incident management, especially police and emergency services.
- Establish a planning team to progress planning and management of incidents.
- Obtain a clear understanding of each stakeholder's objectives and priorities.
- Identify the needs and drivers of incident management as part of the planning process.
- Develop agreed objectives and desired outcomes, understanding the competing objectives of the various responders.
- After evaluating options for delivering the desired objectives, develop a strategic framework, including strategic actions and performance measures and targets.
- Having agreed on the strategic framework, develop a multi-year action plan or program for implementation, detailing strategies, actions and performance measures for the medium to longer term.
- Undertake planning for incident response, including use of micro-simulation modelling.
- Consider incident prevention or risk assessment procedures for incident management.
- Have an annual business plan detailing specific projects, initiatives and ongoing programs to be accomplished, supported by agreed processes to obtain funding.
- Identify what measures will be tracked and used to measure program performance, establish targets and have agreed methods to collect, track and report performance measures.

5.1.6 Incident Detection and Verification

Detection is the process of collecting data and determining that an incident has occurred and obtaining sufficient information or 'intelligence' to determine the appropriate response. A summary of incident detection techniques and their advantages and disadvantages is given in Table 5.2.

Table 5.2: Incident detection/verification techniques

Detection method	Description	Advantages	Disadvantages
Automatic incident detection (AID) – utilising traffic systems, e.g. CMCS, SCATS, STREAMS, video and Bluetooth-based systems	Algorithm software compares traffic data from detectors (loops, infrared, video, vehicle identification, video, Bluetooth) to 'normal' traffic. Variety of statistical and analytical methods available, with varying degrees of reliability. It can also include detection of non-moving vehicles by means of video incident detection.	• Automatic detection – alarm system provides decision support.	• Need coverage of detection devices (loops at say 500 m on freeways). • Balance time to detect, with detection rate and false alarm rate. • Need to verify using camera or other means.
Traffic congestion display systems	Congestion displays and alarms can automatically indicate potential incidents.	• Utilises existing infrastructure for traffic control.	• Need coverage of detection devices (loops at say 500 m). • Need integrated system, using information from traffic system, ramp metering, etc. • Need to verify using camera or other means.
Cameras (CCTV)	Pan-tilt-zoom cameras, at least on major traffic routes and critical locations are particularly important for hazardous locations such as tunnels.	• Readily able to verify incidents (also able to monitor traffic). • Can use video detection.	• Cost of equipment, communications. • Impossible to monitor every camera manually.
Emergency phone call (in Australia 000 or 112 on mobile phone, in New Zealand 111)	Public and motorists report incidents to emergency call centre and are connected to emergency services who subsequently advise the road agency (most common means of detection).	• Low cost (to road agency). • Operate 24 hours every day. • Can verify incident when multiple calls received. • Quick advice about incident in high traffic areas, usually less than one minute in peak traffic periods.	• Depends on public calls – for most serious incidents the number of calls is very high. • Usually need to verify information to clarify location, severity and extent. • Need call centre to provide timely information to road agency – either voice, fax or electronic. • Multiple call centres, e.g. police, fire, ambulance – require coordinated information.
Traffic report hotline	Public and motorists report incidents to transport or traffic call centre.	• Fast detection. • Can verify incident when multiple calls received – plus can use CCTV if available. • Relatively economic detection process as call centre has multiple uses.	• Need to operate in high traffic periods, preferably 24 hours every day (resourcing implications). • Depends on public calls to traffic hotline (education). • Need to verify and improve quality of information, clarify location, severity and extent. • Multiple call centres, e.g. police, fire, ambulance, traffic getting same/ different information.

Detection method	Description	Advantages	Disadvantages
Roadside emergency phone	Devices located at regular intervals – usually on major traffic routes only.	• Clear purpose – direct connection to call centre. • Accurate location of phone known. • Available 24 hours every day.	• Depends on public calls. • Usually need to verify information to clarify location, severity and extent. • Need call centre to provide timely information to road agency – either voice, fax or electronic. • Cost to install/ maintain – becoming less used with proliferation of mobile phones.
Incident response units, contracted towing services	Special vehicles or towing services patrol high traffic/ incident sections in peak periods.	• Detect and verify by credible source. • Provide timely intelligence enabling appropriate response. • Early response – able to fix minor incidents.	• Resourcing implications of funding incident response services – time and areas able to be patrolled depends on ongoing commitment of resources. • Traffic congestion limits access for services. • Responder safety issue for response services on high speed roads.
Police patrols	Peak period patrol on critical high traffic sections.	• Detect and verify by credible source. • Provide timely intelligence. • Quick access. • Early response. • Recognised authority by motorist.	• Resourcing implications of funding special service. • Responder safety issue on high speed roads. • Difficult access in congested conditions.
Incident watch	Professional drivers – road agency, taxi, couriers, tow trucks, buses.	• Informed sources. • Wide coverage of the road network.	• Need education to engender useful level of response. • Still need verifying depending on credibility.
Mayday	Vehicles transmit distress signal triggered automatically.	• Automatic. • Fast. • Accurate location (GPS).	• Limited deployment – currently only in high end vehicles or consumer paid service. • Private call centre needs to relay message.
Aerial traffic monitor	Traffic reporting services use aircraft during peak periods.	• Broad coverage. • Able to review trouble spots.	• Commercial interests. • Limited to peak periods only.

Source: Austroads (2007a).

Much recent research and development work has focused on AID algorithms, primarily applied to motorways (or controlled access roads) and still developing for arterial roads that are much more complex. Automated detection processes traffic data and provides an alarm, allowing an operator to focus on a few events that may be potential incidents. There are a number of different types of algorithms including comparative, statistical, time series and artificial neural network models (which are trained to recognise patterns). The performance of these algorithms is measured in terms of detection rate, time to detect and false alarm rate. Current algorithms result in 90% of incidents being detected with a false alarm rate less than 1% (Austroads 2007a).

Notwithstanding the effort going into automatic incident detection, given the availability of mobile phones, the predominant means of detecting incidents in areas with reasonable levels of traffic is calls from motorists. However, the information from these calls may be inaccurate or incomplete to enable a rapid, effective response.

Incident **verification** confirms that an incident has occurred, refines information on the location and obtains the best possible information on the nature, extent and severity of the incident to enable an effective response.

Verification of traffic incidents is initially conducted by the relevant emergency services communication centre (i.e. police, fire, ambulance), usually by obtaining advice from the first on-site responder emergency service personnel. This enables a credible information source that can provide relevant advice on response and access requirements. The disadvantage is that it may take some time for the first responder to get to the scene.

Methods that are used to verify incidents include:

- CCTV in traffic control centres
- field units – police or emergency services personnel at the incident site, incident response unit
- other means including aerial surveillance by traffic report services.

The objective is to verify the occurrence of a traffic incident as quickly as possible, confirm an accurate location and determine the type, extent and severity of the incident so that an appropriate response can be made.

Incident detection and verification: recommended practice

- Develop and maintain strong working relationships with other organisations that have an incident detection capability – primarily emergency services (police, fire, ambulance), but also radio and television traffic reporting services – to ensure rapid provision of relevant information. Establish protocols and agreements on exchanging data and information on traffic incidents.
- Encourage the provision of real-time data on traffic incidents from emergency services computer aided despatch systems.
- Provide detection and surveillance capability across the network to cover locations or corridors which experience high incident rates – vehicle detectors to be able to monitor traffic speeds and flow, software to automatically analyse and alert potential incidents and trigger visual monitoring, CCTV cameras to verify incidents.
- Provide location reference markers at regular intervals (e.g. at 250 m intervals) on high traffic routes to enable more accurate location of incidents and provide more accurate direction for responders. Alternatively, ensure all responders have GPS devices.
- Consider using a number of alternative or complementary detection methods, including automatic incident detection, video detection, use of mobile phones or toll tags as means of providing more accurate, timely traffic data.
- Ensure provision of systems for rapid incident detection in tunnels. In major tunnels consider multiple systems, e.g. automatic incident detection and video detection and verification.
- Provide traffic and incident information to emergency services, e.g. provide video feed from cameras to police communications and crash investigation units, provide electronic real-time congestion maps to emergency services to enable them to determine less congested access routes.
- Deploy incident response services in high incident times and locations, to also act as first responders and provide detection and verification information to traffic and emergency control centres. Ensure quality communication channels are available which can include radio, phone, wireless Internet (video, email), pagers, and mobile video cameras for responders.
- Build a ‘traffic incident watch’ capability with road agency staff, police patrols, and professional driver groups such as taxi, bus and truck operators.
- Educate the travelling public about how and what to report on traffic incidents – provide a traffic hotline which can also provide up-to-date traffic reports.
- Actively seek innovations to reduce the time to detect and verify traffic incidents including time taken to be notified by emergency services. Monitor and report time taken to detect and verify incidents.

5.1.7 Response to Traffic Incidents

Incident response is the initial activation of an emergency response and directing necessary resources to an incident scene to provide care to the injured and restore the roadway to normal operation.

Incident response and subsequent site management will usually involve more than one agency. It is essential that there be a clear understanding by each agency of its roles and responsibilities. Typical arrangements are shown in Table 3.3, although detailed operational arrangements between organisations may differ between jurisdictions.

Timely response is important because it:

- reduces total incident duration
- saves lives by expediting ambulance services and reduces the long-term impact of injury
- reduces the probability of secondary incidents.

The primary goal is to ensure timely delivery of correct resources to the incident scene, which requires:

- accurate assessment of the scope of the problem, and ongoing assessment
- knowledge of resources available and capability of responder agencies, current status and availability.

Pre-planned response protocols, which can be written up as an incident response manual are valuable for training new staff and act as a reference. A manual could include:

- details of agreed inter-agency protocols
- documented standard procedures
- communication protocols
- contact information
- resource lists
- data collection requirements
- diversion warrants and plans
- pre-configured signal timing changes
- standard traveller information messages
- signal pre-emption protocols for emergency vehicles.

Response procedures provide the following benefits:

- reduce confusion and duplication of effort during the critical period of initial incident response
- utilise best practice
- clarify roles and responsibilities
- remain current if updated as better ways are identified or lessons learned
- ensure legal requirements are covered
- provide guidance on how to handle special circumstances.

Incident response services are generally provided by a combination of incident response units (IRUs), road maintenance crews and towing and incident clean-up services.

Incident response: recommended practice

- Establish response procedures, including standard responses to broad categories of incidents. Consider the range of possible incidents that can arise, as planning ahead saves time when a response action is required.
- Undertake multi-agency training to develop understanding of response protocols and improve communication and understanding of roles and responsibilities.

- Utilise automated decision support information, providing operators with lists and contact details of key personnel, equipment and materials, by geographic area.
- Develop agreed communication and response protocols between agencies. Ensure good communication between control centres, responder agencies and responders to enable a coordinated initial response and traffic control to support ambulance and fire rescue. Inter-agency training exercises develop understanding of technical processes, jargon and procedures.
- Obtain compatible communications systems for all responders (centre-to-responder and responder-to-responder), plus alternatives in the event of technology failure, e.g. multiple phone carriers, back-up radio systems, alternative power sources.
- Establish systems to provide police and emergency services with information on the least congested route to and from the incident scene and provide signal priority if warranted.
- Utilise dedicated incident response services suitably staged throughout the network, preferably covering high incident locations and times, to be able to respond quickly to incidents and provide first response requirements to make the scene safe.
- Consider using police motorcycle patrols during high traffic/incident periods/locations to provide quick, authoritative response.
- Establish targets and performance measures for the time taken between verification, despatch of response and arrival of first response at the scene.
- Provide appropriate incident support systems for traffic management centre operators, that enable them to provide decision support and log events, coordinate incoming information with maps, camera vision, traffic management systems, current traffic conditions and locations of incident response units (using GPS) and also manage variable message signs, variable speed limit signs, telephone hotlines, internet and media traffic reports.
- Ensure appropriate numbers of experienced operators are available for peak periods to deal with the expected volume of incidents, including facilities for handling major incidents with combined multi-agency teams.
- Consider establishing procedures, developed in partnership with incident responders, such that the first responders from any emergency service are responsible for making the scene safe until road agency staff arrives.
- Provide early notification to responders that require long lead times, such as crash, hazmat and heavy vehicle regulation investigation teams, heavy vehicle salvage services, specialist clean-up equipment.
- Incorporate learning and update procedures from debriefs after each major incident.
- Consider procurement and deployment of portable communication facilities for major incidents, where warranted, such as a mobile control centre or cameras.

5.1.8 Traffic Incident Site Management, Investigation and Clearance

Site management

Site management is the management of resources to remove the incident and reduce the impact on traffic flow. It involves coordination of activities by various responding agency personnel and provides for safety at the incident scene. Detailed information is available in Commentary 4.

[see Commentary 4]

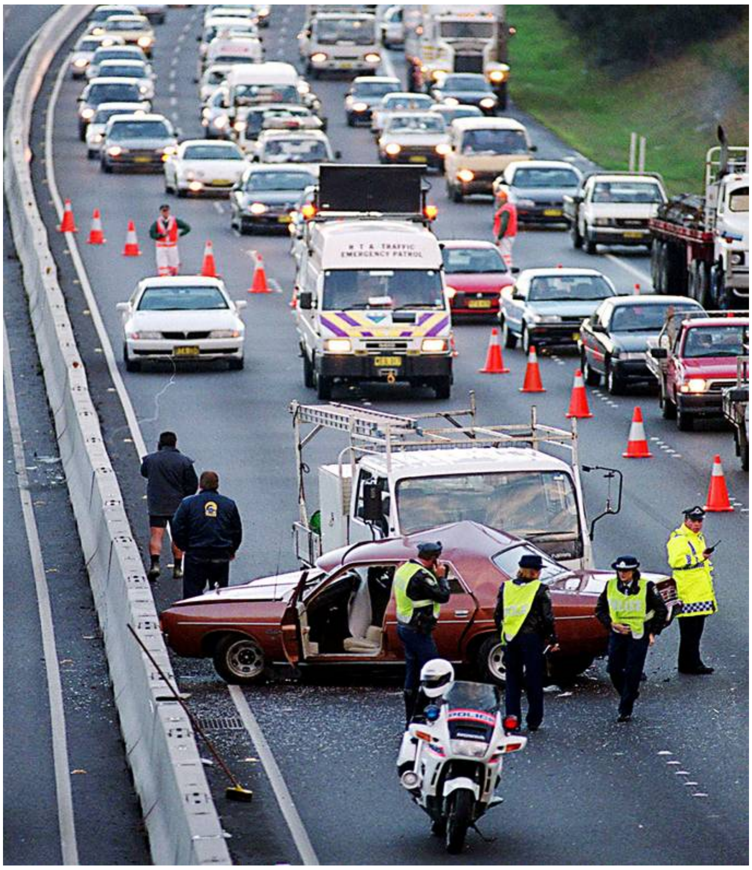
One of the key tasks in incident site management is controlling traffic at the scene, particularly to maintain responder and public safety. Maintenance of traffic flow around the incident scene, once the injured have been attended to, is also an important means of reducing congestion and delay and reducing the risk of secondary incidents.

Application of traffic control measures near the incident scene can be initially undertaken by the first responder whether police, fire or incident response unit. Limited availability of traffic control devices to first responders may restrict the standard to which this can initially be done but it is important to get traffic moving, safely, as soon as possible and this can be achieved through positive traffic control – providing clear delineation of the path through an incident scene and having a controller continuously directing traffic past the scene. This achieves the objectives of both getting traffic moving and maximising safety.

Figure 5.3 shows an example of site management and traffic control measures being applied at the site of a crash.

Incident scenes should be considered as temporary work zones, with all the attendant requirements of using the appropriate traffic control devices as quickly as they can be made available, allowing sufficient buffer zones for responder safety and emphasising traffic awareness for responders.

Figure 5.3: Incident scene – site management



Source: Roads and Traffic Authority (unpublished).

Investigation

Investigation aims to document the causes of traffic incidents, to assign liability for any damages, fulfil the requirements of insurance, to provide data for traffic engineers, and for serious traffic crashes involving serious injuries, fatalities, or suspected criminal activities, evidence is required to be collected and reported to the coroner.

Investigation techniques range from manual measurement through to sophisticated technology to assist gathering of data for analysis and reporting. Use of appropriate cost-effective technology can dramatically reduce the time required to collect evidence and hence reduce the time the road is closed to traffic.

Incident clearance

Incident clearance is the safe and timely removal of any stalled vehicles, wreckage, debris, or spilled material from the roadway and its shoulders and the restoration of the roadway to its full capacity. Incident clearance is typically the most time-consuming step in the incident management process – in the order of twice the duration of other steps in the process. More information is available in Commentary 5.

[see Commentary 5]

Site management, investigation and clearance: recommended practice

- Agree upon a protocol for who controls the site/event: the inner cordon (i.e. immediate incident scene) and outer cordon – (area surrounding the outer perimeter of the incident scene) managing traffic around the incident scene.
- Build stronger partnerships and operating procedures between key responders and develop inter-agency agreements aimed at improving quick clearance through joint operations protocols.
- Establish an agreed, high level, aggressive quick clearance or open roads policy at government level, enact quick clearance laws and regulations – giving authority to clear traffic lanes, limiting or avoiding liability, recovering costs and providing incentives to road users.
- Establish quick clearance targets, such as clearance of all incidents within 90 minutes.
- In tunnels, rapid response to incidents is critical. Consider a dedicated incident response and clearance capability.
- Improve crash investigation procedures and provide appropriate technologies to ensure accurate, timely investigation.
- Introduce innovative public-private partnerships that facilitate incident clearance and provision of traffic information – such as performance based towing/salvage contracts.
- Hold formal systematic debriefs to provide feedback and ongoing improvement.
- Collect and analyse better data and information.
- Contract heavy towing/salvage equipment on stand-by during peak periods.
- Conduct post-incident debriefings (soon after major incidents) to evaluate and refine existing protocols and procedures.

5.1.9 Traffic Management and Traveller Information

Traffic management at the incident site

Traffic management is the application of traffic control measures at the incident site and on the road network affected by the incident. The goals are to minimise traffic disruption while maintaining a safe workplace for responders. Traffic control measures can be categorised into those that are intended to improve traffic flow past the incident scene and those that are intended to improve traffic flow on alternative routes.

Techniques to improve flow past the incident include the following:

- establishing active traffic control at the scene
- managing road space (opening and closing lanes, blocking only the portion of the incident scene that is needed).

Techniques to improve traffic flow on alternative routes include:

- actively managing traffic control devices (including traffic signals) in the areas where traffic flow is affected by the incident
- designating, developing, and operating alternative routes.

Next to caring for the injured and ensuring public safety, maintenance of traffic flow around the incident scene should be of highest priority during the site management process. Traffic control is often not the primary concern of most responders.

Traveller information

Traveller information involves activating various means of disseminating incident-related information to affected motorists. Media used to disseminate motorist information include commercial radio broadcasts, variable message signs (VMS), telephone information systems and the internet or on-line services. Motorist information needs to be disseminated as soon as possible and until traffic flow is returned to normal conditions.

Types of traveller information include:

- internet websites, with traffic reports, camera images, travel times, roadworks and events
- traffic broadcasts on commercial radio, through commercial providers, e.g. Australian Traffic Network
- traffic hotline – with recorded messages of current incidents and roadworks, plus the ability to report incidents
- other means, such as in-vehicle (RDS TMC), SMS messaging, wireless/email
- variable message signs – directing travellers to traffic hotline for specific information relative to the location and delays associated with incidents, plus suggesting alternative routes to avoid congestion.

Traffic management and traveller information: recommended practice

- Use traffic management centres to coordinate incident notification and response.
- Have specific policies and procedures for traffic management during incident response, e.g. active traffic control at the scene, managing road space, diversion plans, and signal timing changes.
- Identify alternative routes across the network and develop maps, diversion signs, revised signal timing, etc.
- Train all responders in effective traffic control.
- Improve communication channels to provide accurate, timely traffic information to road users.
- Utilise real-time motorist information systems providing incident-specific information to road users.
- In tunnels, where real-time information can be critical to tunnel users in an emergency, consider a system to over-ride broadcast radio.

5.1.10 Performance Measures

Road agencies generally collect information about all aspects of traffic incidents (such as the arrival and departure times of all response vehicles) and use performance measures to quantify the effectiveness of the overall incident management process. Measures used include number (or frequency) of incidents, detection time, response time and clearance time.

A possible framework for performance measurement which looks at inputs, processes and outputs is shown in Table 5.3.

Table 5.3: Performance measurement framework

Item	Input	Process	Output
Incident management	Detection and verification.	Response, performance evaluation and review.	Minimise traffic delays; maintain safety.
Potential measures	Number of incidents (by category: major, intermediate, minor). Time to detect, verify.	Response time of responders. Response time (detection to activation). Number of traffic diversions. Time to clear incidents. Duration of incidents. Number of responses to enquiries. Lane-loss time. Relationships with responders. Major incident debrief/audit.	Delays due to incidents. Secondary incidents. Customer satisfaction (complaints, media reports).

Source: Austroads (2007a).

5.2 Planned and Special Event Management

Planned incidents are a special type of incident: their occurrence is known in advance. This provides the opportunity to manage their effect on the road network with much greater certainty than for other incidents. The term ‘special event’ is used here to mean a planned incident of significant size or complexity.

Planned incidents can be divided into the following categories:

- special events
- road developments
- road occupancies.

5.2.1 Special Events

A special event (in traffic management terms) is any planned activity that is wholly or partly conducted on a road, requires multiple agency involvement, requires special traffic management arrangements, and may involve large numbers of participants and/or spectators. Examples are marathons, fun runs, cycling events, parades, marches and street market days.

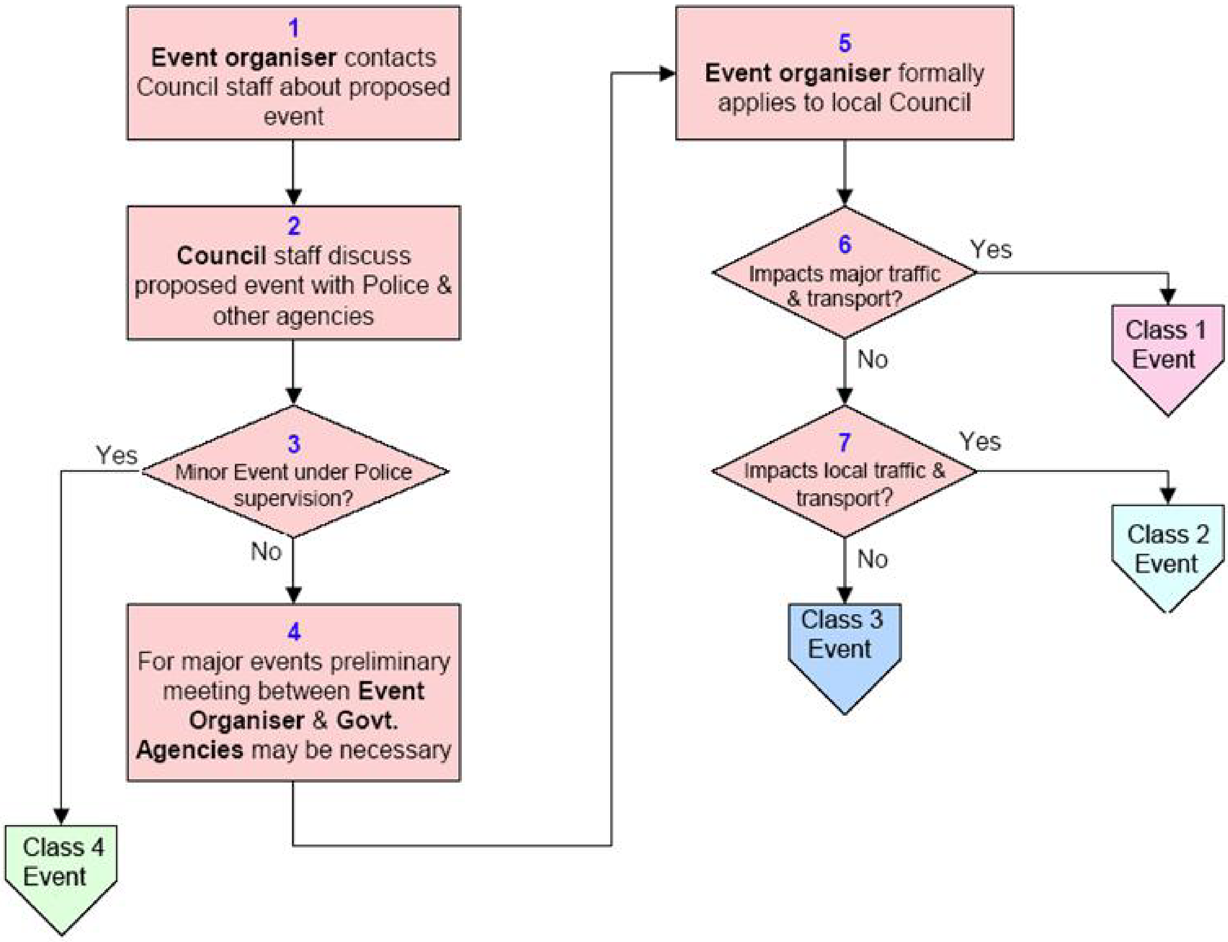
The definition also applies to events conducted in their own venue if the event requires special traffic management arrangements and multiple-agency support.

Special event planning

Special events may range in scale and impact from the large, e.g. a marathon run impacting on principal transport routes in a city, to the small, e.g. a neighbourhood street party. How they are managed from a traffic perspective clearly will depend on the scale of the event, as will the number of agencies that need to be involved in its planning and subsequent management. The scale also determines the extent and degree of planning required to address the traffic aspects.

Figure 5.4 shows a typical process for dealing with a special event application. The objective at this point is to determine the scale of the event and the planning processes that will therefore need to be followed. Note that it involves relevant agencies at an early stage. Note also that different jurisdictions may have different agency roles and requirements, particularly regarding the initial point of contact by event organisers.

Figure 5.4: Special events – process overview



Notes:

Event classification in this example follows the model in Table 5.4.

Different jurisdictions may have different agency roles regarding the initial point of contact by event organisers.

Source: Adapted from Roads and Traffic Authority NSW (2006).

Table 5.4 offers one model for categorising special events, and shows a planning matrix for each class of event. Note that this is only one of a number of possible models. Different jurisdictions may have different agency roles and requirements, but the matrix in Table 5.4 is indicative of the planning issues that must be addressed.

Other issues that may be included for each event class in the matrix are:

- lead times required for agency approval (road agency, police, local government)
- requirements for fees for each agency (where applicable)
- the need for liability insurance.

Table 5.4: Special event planning matrix

Event class	Description	Features	Examples	Transport management plan	Risk management plans (traffic control) under OH&S	Advertise transport management arrangements	Special event clearway heavy vehicle detours	Public trans port	Emergency vehicle and local access	Parking	Contingency planning
1	A Class 1 event: • impacts major traffic and transport systems • disrupts the non-event community over a wide area • requires the involvement of the road agency, police and one or more local government authorities • requires a detailed transport management plan • requires advertising the event's traffic aspects to a wide audience.	A Class 1 event may: • be conducted on-road or in its own venue • involve trusts or authorities when using facilities managed by them • involve public transport authorities and/or providers • impact on the road transport industry • require the road agency to provide special event clearways • require the road agency to provide heavy vehicle detours • require the road agency to adjust traffic signals • require the road agency to manage variable message signs.	For example: • an event that affects a principal transport route in a capital or regional city • an event that reduces the capacity of the main highway through a country town.	Transport management plan required. Model transport management plan recommended	Traffic control layouts drawn up by a qualified person and installed under the guidance of a qualified person. Need to consider access for disabled persons.	28 days for all events that require regulation of traffic or where special event clearways in operation. Not required where there is no regulation of traffic.	Road agency arranges if required. Conditions may apply.	Promo ted where practic able.	Required – refer to transport management plan.	May be required. Refer to transport management plan. Need to consider parking for disabled persons.	Recommended

Event class	Description	Features	Examples	Transport management plan	Risk management plans (traffic control) under OH&S	Advertise transport management arrangements	Special event clearway heavy vehicle detours	Public trans port	Emergency vehicle and local access	Parking	Contingency planning
2	A Class 2 event: • impacts local traffic and transport systems but not major traffic and transport systems • disrupts the non-event community in the area around the event but not over a wide area • requires the involvement of the police and the local government authority • requires a detailed transport management plan • requires advertising the event's traffic aspects to the local community.	A Class 2 event may: • be conducted on-road or in its own venue • involve trusts or authorities when using facilities managed by them • involve public transport authorities and/or providers.	For example: • an event that blocks the main street of a town or shopping centre but does not impact a principal transport route or highway • a motor rally on local country roads.	Transport management plan required. Model transport management plan recommended.	Traffic control layouts drawn up by a qualified person and installed under the guidance of a qualified person. Need to consider access for disabled persons.	28 days for all events that require regulation of traffic or where special event clearways in operation. Not required where there is no regulation of traffic.	–	Promo ted where practic able	Required – refer to transport management plan.	May be required Refer to transport management plan. Need to consider parking for disabled persons.	Recommended

Event class	Description	Features	Examples	Transport management plan	Risk management plans (traffic control) under OH&S	Advertise transport management arrangements	Special event clearway heavy vehicle detours	Public trans port	Emergency vehicle and local access	Parking	Contingency planning
3	A Class 3 event: • does not impact local or major traffic and transport systems • disrupts the non-event community in the immediate area only • requires local government authority and police consent • is conducted on-street in a very low traffic area such as a dead-end or cul-de-sac • requires police agreement that the event qualifies as Class 3 • is never used for vehicle races.	A Class 3 event, depending on local government authority policy, may: • require a simplified transport management plan • not be available in all local government areas • require advertising the event's traffic aspects to the community.	For example: • an on-street neighbourho od Christmas party.	Local government authority may require a transport management plan.	Traffic control layouts drawn up by a qualified person and installed under the guidance of a qualified person. Need to consider access for disabled persons.	28 days for all events that require regulation of traffic. Not required where there is no regulation of traffic.	–	–	Required – refer to transport management plan.	–	–

Event class	Description	Features	Examples	Transport management plan	Risk management plans (traffic control) under OH&S	Advertise transport management arrangements	Special event clearway heavy vehicle detours	Public trans port	Emergency vehicle and local access	Parking	Contingency planning
4	A Class 4 event: • is intended for small on-street events • requires police consent only • is within the capacity of the police to manage on their own • is not a protest or demonstration • is always an on-street event • does not require local government or road agency approval • does not require advertising the event's traffic aspects to the community • does not require a transport management plan • does not require the involvement of other government agencies.	A Class 4 event may: • be conducted on classified or unclassified roads • cause zero to considerable disruption to the non-event community • cross local police and local government boundaries • require local government and/or the road agency to assist when requested by police.	For example: • a small ANZAC Day march in a country town • a small parade conducted under police escort.	–	–	–	–	–	–	–	–

Source: Adapted from Roads and Traffic Authority NSW (2006).

Appendix A shows an example of a transport management plan template (Roads and Traffic Authority NSW 2006). It illustrates the planning requirements for the top three classes of special event, using the event classifications described in Table 5.4. Appendix A functions as a high level planning checklist, ensuring that the following traffic and transport issues are addressed:

- location and routes
- parking
- impact of and on construction, traffic calming and traffic generating developments
- public transport
- re-opening of roads after the event
- traffic management requirements unique to the event
- heavy vehicle impacts
- special event clearways
- contingency plans.

Note that all events, other than very minor ones which, in the example classification require only police approval, require a traffic control plan (TCP) which details the use of traffic control devices (e.g. signs, barriers) to ensure the safety of road users during the event. This would normally be required to be of the same standard expected of a TCP for roadworks. Australian Standard AS 1742.3 and CoPTTM[1] provide details of traffic control devices and layouts which can form the basis of a special event TCP. It may also be a requirement that the TCP is prepared by a qualified person where the jurisdiction operates such qualification schemes.

The TCP can be seen as a risk management plan, demonstrating by its standard and its preparation by qualified personnel that the event organiser is discharging the duty of care (in this case to road users) required under common law or legislation.

There are a number of resources that can assist the preparation of transport management plans and TCPs. In particular the US Federal Highway Administration (FHWA) has a comprehensive series of checklists in its manual *Managing Travel for Planned Special Events* (Latoski et al. 2003) which is available from the FHWA web site. Appendix B shows some of the checklists. Another checklist, shown in Appendix C, draws on the example of the Hamilton, New Zealand, V8 street race to show the range of issues requiring consideration.

Event management

During the execution phases of a special event each agency provides appropriate support as negotiated during the planning phase. It is important to note that the operational conduct of an event largely remains the responsibility of the event organiser though the overall command of an event is vested in a command group.

5.2.2 Road Occupancy

Another class of planned event is road occupancy. A road occupancy consists of any activity (other than a special event as defined in the preceding section) likely to impact on the operational efficiency of the road network, in other words, an activity that requires the road to be used in such a way as to affect traffic flow, or an off-road activity that affects traffic flow. Road occupancy usually involves the closure of one or more traffic lanes.

1 Code of Practice for Temporary Traffic Management (NZ Transport Agency 2004).

Examples of road occupancies are:

- road construction
- road maintenance such as re-surfacing, or line-marking
- public utility installation and maintenance
- lane closures around a building site (as a hazard reduction) or to get cranes or other equipment in and out
- filming activities involving lane/road closures
- grass cutting along a median strip possibly requiring the road shoulder or a lane to be closed.

Road occupancy approvals

Most road agencies operate a road occupancy licensing scheme to regulate the temporary occupation of road space, ensuring that traffic management requirements are met. The principles underpinning such schemes are:

- the need to maintain traffic flow to an acceptable level of service, involving
  - the number of lanes to be closed
  - the duration and times of closure
- organisational coordination.

Road occupancies undertaken by a road agency itself will usually be subject to an internal occupancy approval procedure whereby the part of the authority responsible for traffic operations will review occupancy proposals of the part that is responsible for the roadworks.

Examples of road occupancy licence applications are shown in Appendix D. They illustrate the matters requiring consideration in ensuring the maintenance of an acceptable level of service and road user safety when roadworks, utility works in the road and other activities having a similar impact on traffic are undertaken. Two examples are given. The first relates to **road development** activities including road construction, road maintenance, traffic signal construction or maintenance and utility works that involve road openings. The common element is that the activities involve the road infrastructure and therefore may require consideration by the asset manager for the infrastructure. The second relates to **non-development** activities such as:

- occupation of a traffic lane to support building construction activities
- mobile crane operation from the roadway
- public utility infrastructure maintenance.

Appendix D also gives an example of a checklist required to be completed by the proponent. It forms the basis on which the traffic impacts of road occupancy can be considered.

Matters to be noted that might affect the impact of road occupancies on traffic flow typically include:

- the presence of traffic signals within 100 m of the site
- effects arising from signal phases (lanes, turning lanes, detection)
- roundabouts within 100 m of site
- the presence of any nearby railway level crossing
- occupancy near a length of road subject to tidal flow (reversible lane) management
- the number of traffic lanes in each direction
- adjacent significant land use with major ingress/egress such as hospitals/schools/supermarkets
- presence of a raised median/divided carriageway

- any kerbside restrictions such as
  - clearways/bus or transit lanes
  - designated parking restrictions
  - loading zones
  - bus stops
  - taxi ranks.

Traffic management plans

Road occupancies should each be the subject of a traffic management plan. The detail of the plan is determined by the impacts on traffic of the occupancy. A traffic management plan integrates an activity into the operation of the road network. The plan assesses an activity's impact on traffic flow. It describes the activities being proposed, their impact on the general area (including public transport passengers, cyclists, pedestrians, motorists and commercial operations), and how these impacts are to be addressed.

The traffic management plan should include details of the work involved, including a work site diagram showing exactly where the work is being performed, vehicle movements around the work site and identifying:

- one-way streets
- lane widths
- numbers of lanes affected and total number of lanes
- traffic signals
- turning lanes
- railway level crossings
- pedestrian crossings
- any other information resulting from a survey of the location.

Traffic management plan: recommended practice

Where applicable, the traffic management plan should describe and/or make provisions for:

- any construction, existing or proposed, that might conflict with the occupancy
- any restricted movements, banned turns, heavy/high vehicle routes
- any traffic calming devices
- whether the occupancy affects sections of road subject to tidal traffic flow (reversible lane) management (usually in the am or pm peaks)
- any impacts on public transport, local residents and businesses, shopping centres, churches, industrial areas, parking stations, public facilities (e.g. football oval), schools, hospitals, etc.
- access of emergency vehicles, heavy vehicles, cyclists and pedestrians (special arrangements should be made by the proponent in conjunction with the affected agency and described in detail and must be endorsed by the affected agency, e.g. police, fire brigade, ambulance)
- the hours during which the occupancy will be in effect: on arterial roads with traffic flows nearing capacity, typified by roads with clearway or peak period parking restrictions, and on roads with bus or transit lanes, road occupancies are not usually permitted other than in an emergency
- the amount of time required, in the event of an emergency requiring a direction to cease works to restore the road to trafficable condition (should be considered and communicated in the traffic management plan)
- whether proposed traffic movement is contrary to any regulatory traffic control device
- significant traffic congestion resulting in increased travel times (detours may alleviate congestion and may include special purpose strategic signage, e.g. variable message signs)

- whether the use of variable message signs (VMS) is required (portable or permanent VMS); the road agency may need to prepare VMS messages warning road users about the traffic impact of the occupancy
- whether it is necessary to advertise traffic management arrangements in local newspapers/media (where an occupancy disrupts access to local businesses and residents, the proponent should carry out a letter box drop to inform the local/affected community about changes to normal traffic conditions and possible disruptions)
- detour routes
- details of the public consultation process (how the community is to be advised of the activities)
- any required changes to speed zone signs requiring road agency authorisation
- required changes to traffic signal operation (the road agency may need to adjust traffic signals and control systems to accommodate the occupancy)
- parking or stopping restrictions
- effects on facilities for the duration of the occupancy or after the occupancy is finished, e.g. disabling traffic sensors
- if the project is to be done in stages, a full description of the work being performed at each stage, as well as its proposed times (e.g. project description is 'water main installation' but the project may have various stages such as:
  - excavation in northbound lanes – proposed times
  - excavation in southbound lanes – proposed times)
- plans for possible issues/risks that may interfere with the road occupancy.

Traffic control guidance plans

A traffic control guidance plan (TCGP) is referred to by different names amongst jurisdictions, including traffic control plan or traffic control diagram. In AS 1742.3, a TCGP is referred to as a traffic guidance scheme. A TCGP is a document that shows how traffic may be safely separated from workers at the work site or work route. It is intended as an instruction from the works supervisors to site crews and is usually in the form of a diagram showing the road conditions (lanes, signs, etc.). It typically includes details of how traffic will be managed around a site or activity by way of temporary signs, barriers, and posting of traffic control staff.

A TCGP is, in most jurisdictions, an occupational health and safety requirement for a work site. The TCGP should comply with AS 1742.3 or CoPTTM to support compliance with the occupational health and safety legislation.

The Austroads report *Implementing Best Practice for Traffic Control at Worksites: Risk Management, Audit and Field Operations* (Austroads 2012) provides practitioners with guidance on national best practice for the planning, design and implementation of temporary traffic control measures at road work sites and is generally in accordance with AS 1742.3.

Some road agencies have developed manuals and codes of practice extending the principles embodied in AS 1742.3 and CoPTTM to a greater range of road situations and activities. These jurisdictions often require the use of these manuals and codes of practice when preparing a TCGP. For some road agencies, a TCGP may be required to be prepared by a qualified person.

6. Systems and Procedures for Arterial Traffic Control – Traffic Signals

6.1 Introduction

This section discusses the application of traffic signal techniques to support the realisation of network operation plans. It also covers the operation of traffic signals, particularly in relation to their detectors and controllers, and provides guidance on the time settings for their operational configuration. It also discusses traffic signal coordination and the operation and configuration of coordinated systems.

Other parts of the Guide to Traffic Management which discuss aspects of traffic signals and signalised include:

- Part 6 (Austroads 2019c) which contains information on the functional design of traffic signals, including layout, road space allocation and lane management.
- Part 10 (Austroads 2019d) which provides guidance on signal aspects and their meanings, signal face layouts, display sequences and signs and pavement markings associated with traffic signals (i.e. those aspects of traffic signals visible to the road user).

Other parts of the Guide to Traffic Management and Guide to Road Design which cover topics relevant to traffic signals and signalised intersections are as follows:

- Part 2 of the Guide to Traffic Management (Austroads 2015a) discusses traffic theory and covers matters regarding queueing and platoon dispersion.
- Part 3 of the Guide to Traffic Management (Austroads 2017c) covers traffic studies and analysis and includes capacity analysis, intersection performance and other analysis procedures pertaining to signalised intersections.
- Part 13 of the Guide to Traffic Management (Austroads 2015f) deals with road safety considerations.
- Part 4A of the Guide to Road Design (Austroads 2017b) details the geometric design of unsignalised and signalised intersections.

6.2 Intersection Signals and the Safe System

Intersection signals should be designed and operated in a way that supports a Safe System. As intersections are where most conflicts between different traffic streams occur (including pedestrian and bicycle traffic) it is critical that geometry and operation of signalised intersections are designed so that, as far as is practically possible, the likelihood of serious crashes is minimised. Managing the likelihood and outcome of crashes at intersections by designing and operating the infrastructure in an appropriate manner is necessary to support the safe roads and roadsides pillar of the Safe System. Traffic signal design and operation must be considered from the road user perspective. For road users, traffic signals are essentially a communication device which, if well designed, will simplify decision making and foster safe behaviour.

While intersection signals have generally been found to improve the safety performance of intersections compared to that of priority-controlled intersections (NZ Transport Agency, 2013), they have not been typically identified and promoted as a Safe System treatment (Austroads, 2015h). This is because the geometric design and operation of signalised intersection is generally not sufficiently forgiving in the event that a driver or other road user makes a mistake. A number of factors that increase the FSI crash risk at signalised intersections are outlined in Section 6.4.3. These factors should be taken into account when designing intersection signals and their operation.

6.3 Traffic Signal Techniques and Network Operation Planning

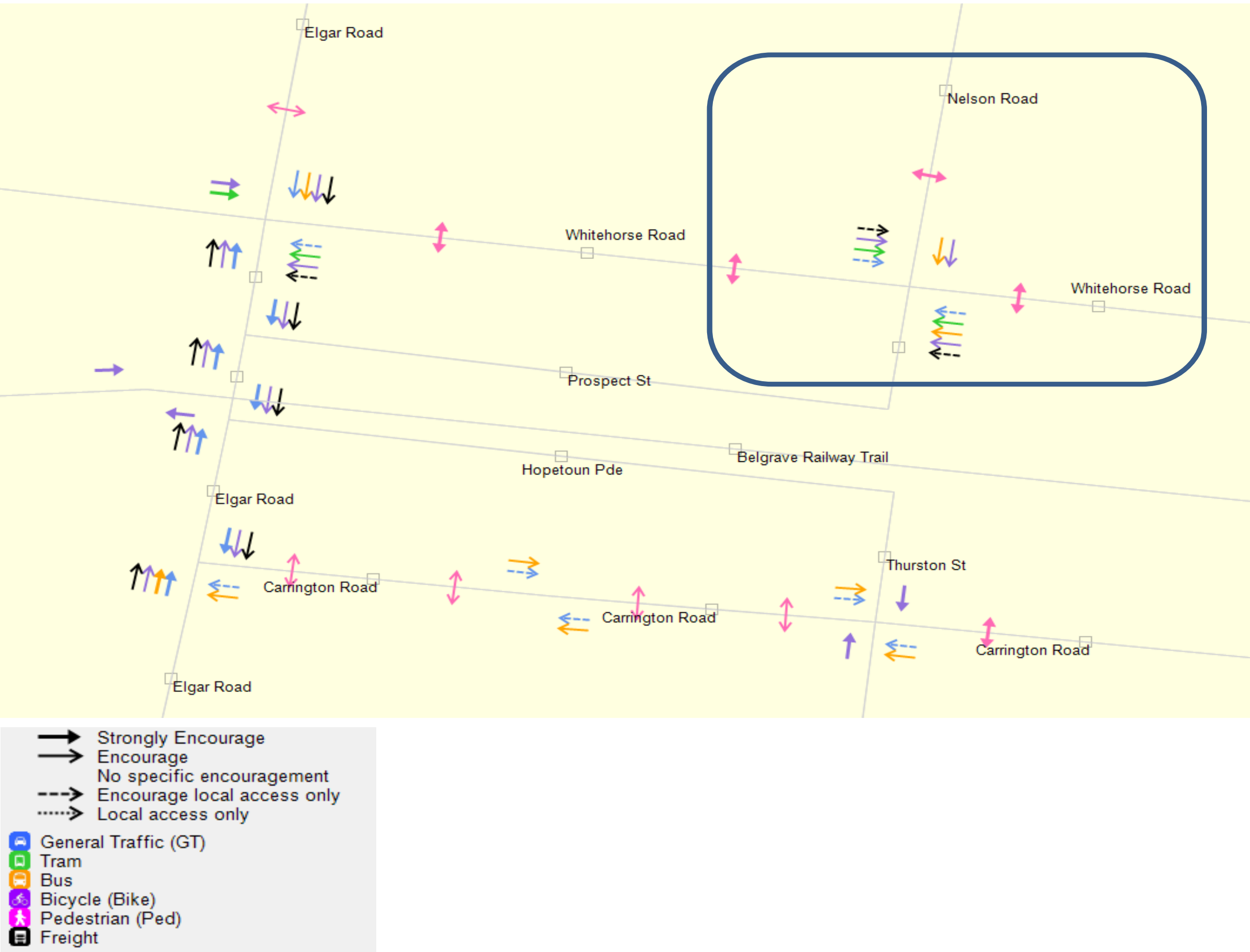
6.3.1 Role in Network Operation Planning

Traffic signals are a fundamental component of network operations, and with increasing congestion and multi-modal use of the network, there is more pressure on signal operators to proactively optimise operations for the benefit of all users. A network operation plan (NOP) provides a framework for signal managers and operators to identify and implement operational treatments that will support the objectives for operation of the road network and manage conflicting modal priorities. For a detailed description of network operation planning refer to the Guide to Traffic Management Part 4 (Austroads 2016a).

Network operation planning establishes the road use priorities for particular road user groups, which can include general traffic, public transport, pedestrians, cyclists and freight. The road use priorities are based on the link and place function of the road and Figure 6.1 is an example. In this example, at the intersection of Whitehorse Rd and Nelson Rd in Melbourne, pedestrian movements have been accorded the highest priority. Cyclist, tram and bus are given the second-level priority while general traffic and freight are provided local access only.

The assigned priorities for each road user determine the aspirational level-of-service (LOS) for the road user group. Table 6.1 shows an example of how the aspirational LOS can be set based on road use priority. It also includes descriptors of LOS developed in Austroads (2015d).

Figure 6.1: Example of road use priority in network operation planning



Source: VicRoads (2013c).

Table 6.1: Relative priority and aspirational LOS

Relative priority	Aspirational LOS	Description of LOS for general traffic (for congestion)
Strongly encourage	A	For arterial roads generally free flow-conditions with operating speeds at least 80% of the free-flow speed. Vehicles are unimpeded in manoeuvring in the traffic stream and delay at intersections is minimal.
Encourage	B	For arterial roads relatively unimpeded flow with operating speeds between 50–80% of the free-flow speed. Manoeuvring in the traffic stream is only slightly restricted and intersection delays are low.
No specific encouragement	C	For arterial roads stable operating conditions but with manoeuvring becoming more restricted and motorists experiencing appreciable tension in driving. Operating speeds are between 30–50% of the free-flow speed. At signalised intersections, vehicles generally have to stop in a queue but clear the intersection in one signal cycle.
Encourage local access only	D	For arterial roads small increases in traffic volumes can significantly increase delay. Operating speeds are between 20–30% of the free-flow speed. At signalised intersections, vehicles always join the back of an existing queue and take about two signal cycles to clear the intersection.
Local access only	D -	–
No priority	E	For arterial roads conditions are characterised by significant delays with operating speeds between 10–20% of the free-flow speed. At signalised intersections, vehicles take three or more signal cycles to clear the intersection.

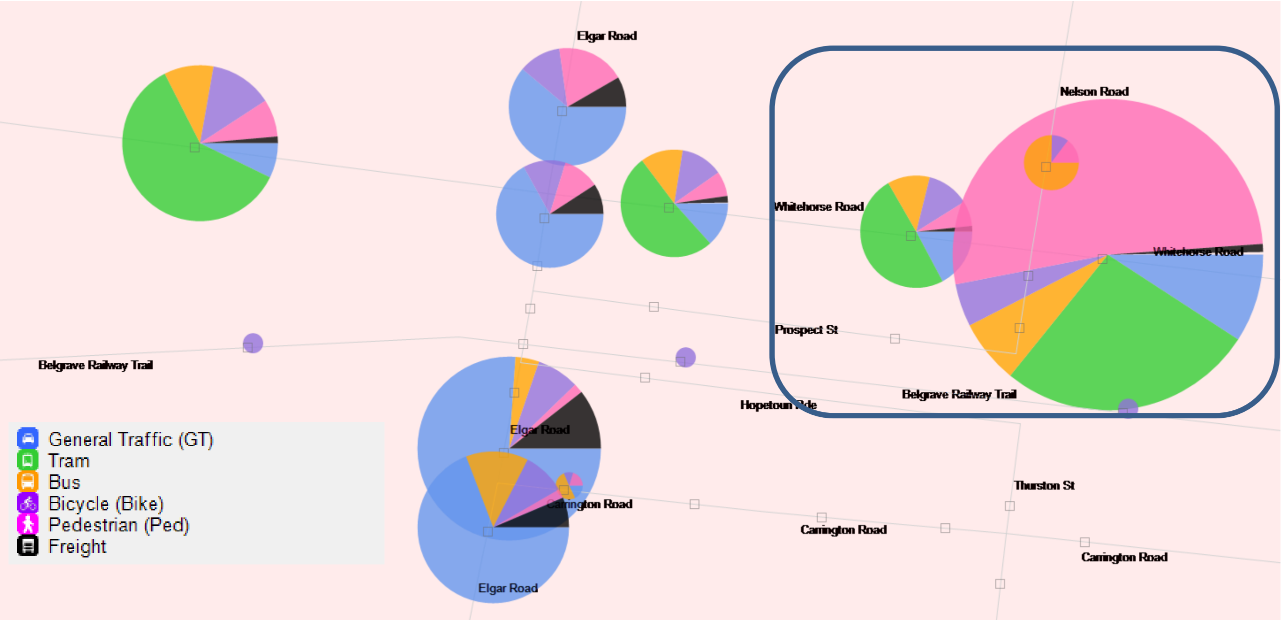
Source: Description of LOS for general traffic (for congestion) is based on Austroads (2015d).

In existing networks, a performance gap in network operation planning is defined as the difference between the existing LOS and the aspirational LOS weighted by the volume of the road users. Figure 6.2 is an example of a performance gap assessment of an intersection. In this example, the intersection of Whitehorse Rd and Nelson Rd is showing a significant performance gap for pedestrians. Traffic signal operation can contribute to the reduction of a performance gap by targeting improvements to specific road user groups. In the example, techniques that improve pedestrian LOS would be most appropriate.

In greenfield networks, network operation planning can also be employed to define operational strategies as part of the context sensitive design approach described in the Guide to Traffic Management Part 4 (Austroads 2016a) and the Guide to Road Design Part 2 (Austroads 2015g). Having a defined operational strategy assists in selecting and designing the most suitable traffic signal operation technique to implement.

Traffic signal techniques that are potentially appropriate for addressing road-user-specific issues are described in the following section.

Figure 6.2: Performance gap example



Source: VicRoads (2013c).

6.3.2 Traffic Signal Techniques to Support Road User Priorities

Traffic signals are one of the tools that can be used to implement road user priorities in a network operation plan. The various traffic signal techniques can be categorised as techniques that support:

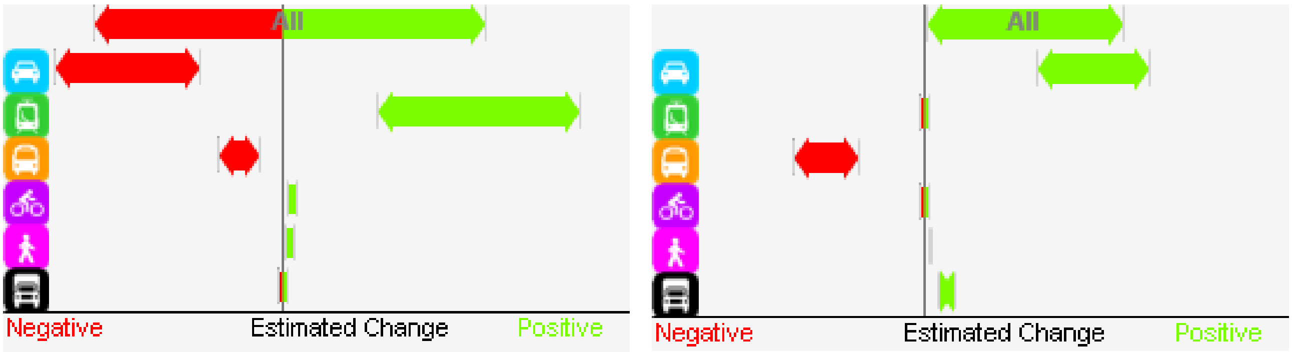
- general traffic priority (Table 6.2)
- public transport priority (Table 6.3)
- freight priority (Table 6.4)
- bicycle priority (Table 6.5)
- pedestrian priority (Table 6.6).

The selection of the most appropriate traffic signal technique to support a network operation plan involves an evaluation of a set of short-listed techniques. The evaluation of these treatment options can be done by 'network fit assessment', described in the Guide to Traffic Management Part 4 (Austroads 2016a). Figure 6.3 illustrates two examples of a network fit assessment result. The left example shows the assessment of a technique that has positive impacts for trams and negative impacts for general traffic as well as buses. On the right is a technique that has positive impacts for general traffic but has negative impacts for buses. The decision on the technique to implement would depend on which addresses the performance gap and the needs of targeted road user groups.

It should be noted that a traffic signal technique can have impacts on other road user groups, as exemplified in Figure 6.3. These impacts can include mobility, safety and to some degree access (i.e. in case of restricted movements). These trade-offs in performance need to be understood in order to conduct network fit assessment. The impacts of treatments on performance gaps are assessed typically through expert-panel judgment. Traffic modelling is applied if resources are available and if a more detailed assessment is desired to give greater confidence in the outcome.

The report *Signal Management Techniques to Support Network Operations* (Austroads 2015e) has developed a toolkit to assist in understanding the scope and scale of impacts of traffic signal techniques. This toolkit (Appendix L) can be used as a reference when conducting a network fit assessment of traffic signal techniques.

Figure 6.3: Examples of a network fit assessment



Source: VicRoads (2013c).

Traffic management considerations at signalised intersections may involve the allocation of road space or lanes to specific road user groups. These are discussed in Part 6 of the Guide to Traffic Management (Austroads 2019c). Part 10 of the Guide to Traffic Management (Austroads 2019d) provides guidance on signal displays and the locating of equipment relating to the modal treatments described.

Many of the modal treatments described in this section may involve complex signal operations. These will require input from specialist signal operations engineers who can provide advice on appropriate phasing sequence options, associated model inputs or other critical elements.

Table 6.2: Signal timing and phasing treatments that support general traffic priority

Traffic signal treatment	Description
Improved signal coordination/progression	Coordinate offsets between different signals to improve progression for general traffic.
Banned right-turns	Prohibit right-turns to improve through movements (either permanently or at peak times).
Skip right-turns every second cycle (peak times)	Skip right-turns every second cycle to improve through movements (e.g. at peak times).
Maximum time transfer/stealing	Although each phase has only one maximum time setting, the maximum time of a given phase can be increased by transferring maximum time from other phases. This provides an automatic method of adjusting the relative allocation of maximum time where traffic flow is particularly tidal.
Gating to an area	Control the inflow and outflow of traffic to prevent serious congestion in sensitive areas where it is particularly important (e.g. city centres). May use downstream detection to lessen the throughput of upstream traffic into a congested area.
SCATS Incremental Split Selection and Variation Routine 83 (for congestion management)	Specific SCATS routines for congestion management. Included in VR83, a spill-over flag is introduced to modify the degree-of-saturation values used for the calculation of signal timings when downstream queue blocking occurs.
Pedestrian parallel walk	Pedestrians cross in parallel with the through traffic movement. Vehicular signal green periods and pedestrian walk periods commence at the same time, with drivers required to give way to pedestrians when turning left/right across the crossing.
Late start for vehicles (early start/leading interval for pedestrians) – partially protected parallel walk	Pedestrian phase is started prior to parallel vehicle phases. Vehicular traffic is prevented from turning across the crossing for the initial part of the pedestrian walk period (i.e. through use of red arrows), subsequent to which, vehicles are allowed to proceed subject to them giving way to pedestrians on the crossing. Hence, pedestrians are protected from turning traffic for the initial part of the crossing period. The late start for vehicles may be implemented as an active measure (e.g. only when pedestrian demand detected). An often used alternative is to restrict turning movements for the full duration of the pedestrian phase, hence this treatment is classified as supporting general traffic.
Pelican crossing	Typically used at mid-block crossings. Applies a flashing yellow phase that enables vehicles to proceed once pedestrians have cleared the crossing. Helps to minimise delays resulting from the flashing don't walk interval operating when no pedestrians remain in a pedestrian crossing.
Two-staged crossing at wide intersections	Provide safe crossing options for pedestrians, while also ensuring vehicular traffic is cleared in time. May be cleared in a single phase or two. Push buttons may be available in the central waiting area to register demand.

Source: Austroads (2015e).

Table 6.3: Signal timing and phasing treatments that support public transport priority

Traffic signal treatment	Description
Green extension/phase extension	Traffic signal extends green period when a bus or tram is approaching to assist with clearing the signalised intersection prior to the red period.
Recall/red truncation or early green/priority green/phase early-start	Where a bus or tram is expected to arrive prior to a green phase, the red phase is terminated early and signal phases are reconfigured to allow the green phase to begin earlier.
Additional phase in signal cycle to clear queues in front of buses/trams	The additional phase is used to clear queues in front of buses or trams so that they can progress through the intersection upon arrival.
Priority phase sequences	A sequence of phases (e.g. special phases and phase extension) may be called to clear traffic from the path of a bus or tram prior to the actuation of the public transport vehicle priority phase itself.
Phase suppression (of conflicting movements)	Phase suppression, or omission of a standard phase in the signal cycle, may occur when a bus or tram priority phase is called. This promotes the allocation of priority to the public transport vehicle. The conflicting movement would be supressed in order to favour the primary movement.
Public transport priority phase with dedicated lanes (full-time or part-time)	Public transport vehicles are detected on a dedicated (permanent or peak-period only) public-transport-only lane, which activates a priority phase that only buses or trams can complete. Also may be referred to as special phase/bus-only phase/tram-only phase.
Public transport priority phase with queue-jump lanes	Public transport vehicles are detected on queue-jump lanes, which activates a priority phase that only buses or trams can complete. Queue-jump lanes are shorter sections of bus-only lanes/tram-only lanes on the carriageway on approach to intersections.
Priority movement repetition in cycle	The movement required by buses or trams is introduced at more than one point in the signal cycle. This technique may be particularly useful at complex intersections with multiple phases and/or long cycle times, and where public transport vehicles cross a major road.
Reduced cycle time	Reducing the cycle time to shorter than that dictated by general traffic can reduce the delay experienced by public transport vehicles. This technique may be particularly effective where public transport vehicles have dedicated lanes and their frequencies are high.
Gating to an area for queue management	Controls the flow of vehicles through the area surrounding critical intersections on a public transport priority route. Improves public transport vehicle travel time, for example by reducing the demand for green time from other traffic movements at critical intersections.

Source: Austroads (2015e).

Table 6.4: Signal timing and phasing treatments that support freight or heavy vehicle priority

Traffic signal treatment	Description
Longer signal cycle times (higher minimum cycle times)	A longer cycle time generally favours truck movements as long as the green time ratio is maintained. A longer cycle time typically can provide a longer green period in a cycle, which allows more vehicles including trucks to pass through an approach irrespective of a truck's position in a platoon. Longer cycle times also minimise the need for trucks to stop and start.
Coordinating signal offsets for heavy vehicles	Selecting offsets to minimise trucks from stopping along an arterial road.
Green extension/dwell phase extension/early start	Traffic signal extends green time to assist heavy vehicles with clearing a signalised intersection. Similar to active priority for public transport, e.g. equip with GPS/transponders or other heavy vehicle detection systems in order to extend or bring forward (i.e. early start) a green phase on detection of approaching truck and to minimise stops.
Ensure that heavy vehicles are able to move from the stop-line and safely clear the intersection	Increasing of clearance times. Refer to Commentary 11.

Source: Austroads (2015e).

[see Commentary 11]

Table 6.5: Signal timing and phasing treatments that support bicycle priority

Traffic signal treatment	Description
Late start for vehicles (early start/leading interval for cyclists)	Bicycle phase is started prior to parallel vehicle phases. An early start positions cyclists where they are more likely to be noticed by motorists when a parallel vehicle phase begins. Typically, the vehicle late start would only be activated if a bicycle is detected (i.e. on a bicycle lane). May be more effectively implemented with lead-in lane and advanced stop boxes.
Fully protected parallel crossing for cyclists at shared path crossing	Green/red (ride/don't ride) bicycle signals are displayed concurrently with the operation of green/red (walk/don't walk) pedestrian signals at a protected parallel shared path crossing. Typically, the cyclist or pedestrian on a shared crossing would be required to press a call button to activate the crossing.
Extended clearance intervals	The clearance time for a bicycle movement may need to be longer than for other traffic (i.e. early cut-off of cyclist movement). A cyclist may travel slower than other vehicles and may not have sufficient time to safely clear an intersection when entering just before the yellow interval. Requires bicycle signal aspects to be used. Can be implemented as a passive and active measure (e.g. via a detector in a bicycle lane).
Longer green time for cyclists at shared path crossings	At shared path crossings, cyclist signals may have a longer green time and a shorter clearance time than pedestrian signals (while the total phase time remains the same), since cyclists move faster.
Exclusive signal phase for cyclists	Simultaneously preventing vehicular traffic on all intersection approaches from entering the intersection to allow cyclists exclusive crossing access.
Activation of green signal phase when cyclists are detected	Detection of cyclists results in activation of green signal bicycle display. Detection may be via cycle request boxes/push buttons or loop detectors. Loop detectors may be installed along cycle routes on approach to major intersections, in cycling facilities adjacent to other traffic lanes, or in advanced stop boxes.
Signal coordination for cyclist priority	In some situations, traffic signal coordination may be provided for the benefit of cyclists. May be considered in specific situations such as on bicycle routes with high cyclist volumes, several closely spaced signals, and a strong tidal flow.
Arterial reversion	In the absence of demands, the traffic signals will revert to a selected stage (e.g. a signal plan for a cycle priority route).
Cyclist bypass lanes at T-intersections	Provide cyclists travelling on the mainline with a green bicycle display at a T-intersection if the side street turning vehicles do not conflict with the cyclist facility at the intersection.
Mid-block crossing signals for cyclists	Provide cyclists with bicycle signal aspects at mid-block pedestrian crossings so that they are not required to dismount.

Source: Austroads (2015e).

Table 6.6: Signal timing and phasing treatments that support pedestrian priority

Traffic signal treatment	Description
Exclusive signal phase for pedestrians	Simultaneously preventing vehicle traffic on all intersection approaches from entering the intersections to allow pedestrians exclusive crossing access. Pedestrian phase is not timed for the diagonal movement. Suitable locations include near major pedestrian-use facilities such as transport interchanges, major sporting/entertainment venues and shopping complexes.
Exclusive 'scramble crossing' or 'Barnes dance' phase	Allows all pedestrian movements, including diagonal movements, to operate simultaneously within the marked limits of the crossing while eliminating vehicle conflicts. Pedestrian phase is timed for diagonal (longest) movement and operates as an exclusive signal phase. Scramble phasing eliminates conflict between pedestrians and turning vehicles and consolidates all pedestrian movements at an intersection into one phase. They are generally good for areas with high pedestrian and turning vehicle volumes.
Double/half cycling	In areas where traffic signals are coordinated and there are high pedestrian volumes, a minor intersection or mid-block crossing may use a cycle time that is half the length of adjacent signals. Reduces pedestrian waiting time, while still allowing for traffic signal coordination.
Dwell on red for all users, or dwell on walk (green) for pedestrians	Traffic signal displays red for all movements until a pedestrian (or vehicle) is detected. Alternatively, a traffic signal dwells on the pedestrian walk interval until a vehicle is detected. May be appropriate during situations where pedestrian volumes are high and vehicle volumes are low (e.g. late at night near areas of alcohol consumption).
Extended clearance intervals	Lengthen clearance intervals for pedestrians at high-volume crossings (e.g. midblock crossings outside schools). Can use active detection.
Extended walk/stretch walk/rest in walk	The pedestrian walk interval is kept as long as possible with the parallel vehicle green signals.
Reduced cycle lengths	Reduce cycle lengths to reduce waiting time for pedestrians in areas of high pedestrian activity (e.g. city centres).
Fixed demand	Controller is set to register demand for a pedestrian movement on every cycle. Should only be considered where and when pedestrian volumes are high (e.g. city centres) to avoid pedestrian phases when there is no pedestrian demand.
Puffin crossing	Additional detectors monitor the progress of pedestrians on a crossing, allowing crossing time to be reduced when a pedestrian has crossed quickly, or extended for slow-moving pedestrians. May aid slower-walking pedestrians and minimise delays due to flashing don't walk interval operating when no pedestrians remain on a crossing. May also apply kerbside detectors to cancel a pedestrian call when pedestrians are no longer present during the walk interval, in order to minimise unnecessary delay to vehicles. Also implemented as intelligent mid-block pedestrian activated crossing. Typically implemented at mid-block crossings.
Isolated traffic controls at areas with high pedestrian demand	The traffic control is isolated instead of being coordinated with others, which may reduce pedestrian wait time by decreasing the signal cycle time or skipping phases. Generally applied to coordinated signals with very long cycle times, where pedestrian level of service is determined to be of higher priority. May only be applicable to certain times of day.
Pedestrian countdown timers	Countdown timers show the time remaining until the end of the pedestrian clearance interval in order to improve pedestrian behaviour at traffic signals and potentially reduce pedestrian delay. Countdown timers may also count down until the next walk interval; however, this type of countdown timer has not been trialled in Australia or New Zealand.
Reintroduction of pedestrian walk	Pedestrian walk interval is reintroduced after the pedestrian phase has timed out on the main road phase, but there is no traffic on conflicting phases.

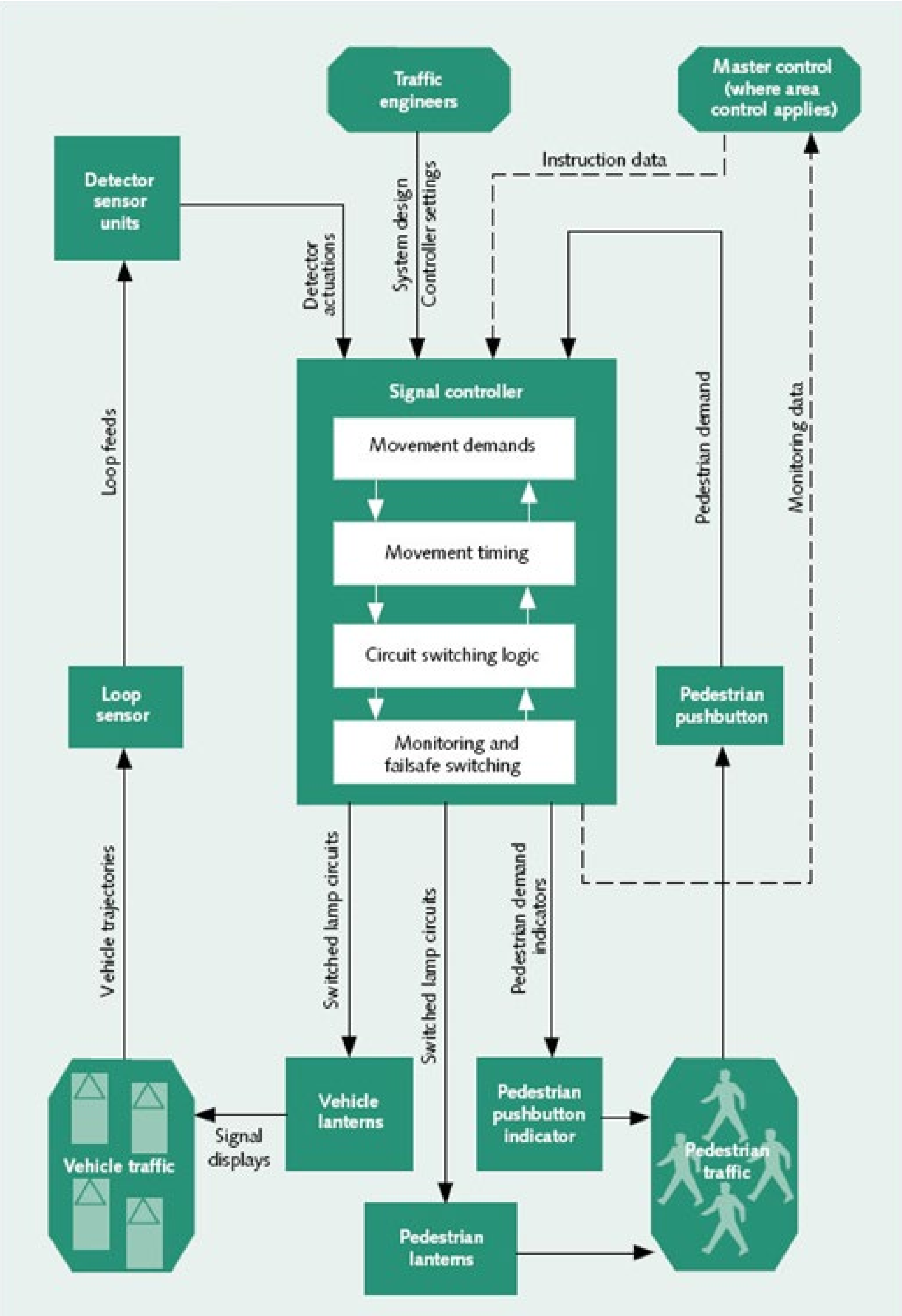
Source: Austroads (2015e).

6.4 System Overview

Figure 6.4 illustrates traffic signal operation from a system process viewpoint. Demands for traffic movements are identified through vehicle detectors, pedestrian push-buttons, and where relevant, externally supplied data from a master control computer. The signal system transforms traffic demands, in a manner determined by the controller algorithms and operational settings, into a sequence of signal displays.

The signal controller consists of a housing containing all the controlling hardware including a logic module and personality. The logic module runs the background software which monitors the inputs from detectors, communicates with the central master computer and drives the outputs to signal displays. Each controller has a unique program called a ‘personality’ which configures the controller to the specific operational design of the intersection or mid-block device it is controlling. The ‘personality’ is an erasable programmable read only memory (EPROM) containing site specific data such as the number of inputs and their function; the logic associated with each input; the number of different outputs and how they operate; and time settings.

Figure 6.4: Traffic signal system process overview



6.5 Movements and Phases

6.5.1 Introduction

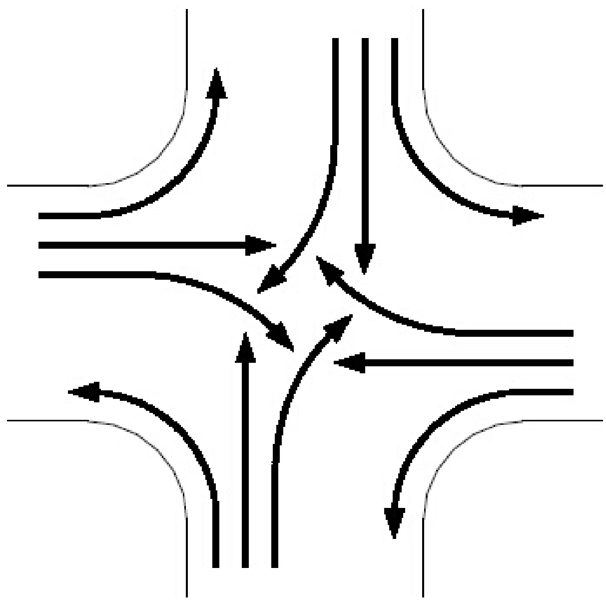
In order to understand the operation of traffic signals it is first necessary to understand the basic concepts of movements and phases.

Each possible trajectory of traffic flow is called a movement. At a typical four-way intersection, each approach to the intersection can accommodate three movements:

- vehicles turning left
- vehicles travelling straight through
- vehicles turning right.

In the simple intersection shown in Figure 6.5 there are three movements in each approach for a total of 12 movements.

Figure 6.5: Vehicle movements at an intersection



The phase is the entity which the controller uses to share time among the various compatible movements. A phase may consist of a set of non-conflicting movements or certain conflicting movements where the priority is defined by traffic regulations. Where a phase contains conflicting movements, those movements which are obliged to give way are said to be filter movements.

The maximum of seven phases operated by a controller are labelled A to G. In some cases, phases may have options within the same phase, e.g. E, E1 and E2. Only one phase can be ‘running’ at any one time. Phases are typically serviced in alphabetical order (although this is not essential) and phases may be skipped if they are not demanded. Selecting a phasing design for a particular intersection depends on the traffic flows of vehicles and pedestrians for each movement.

6.5.2 Phase Intervals

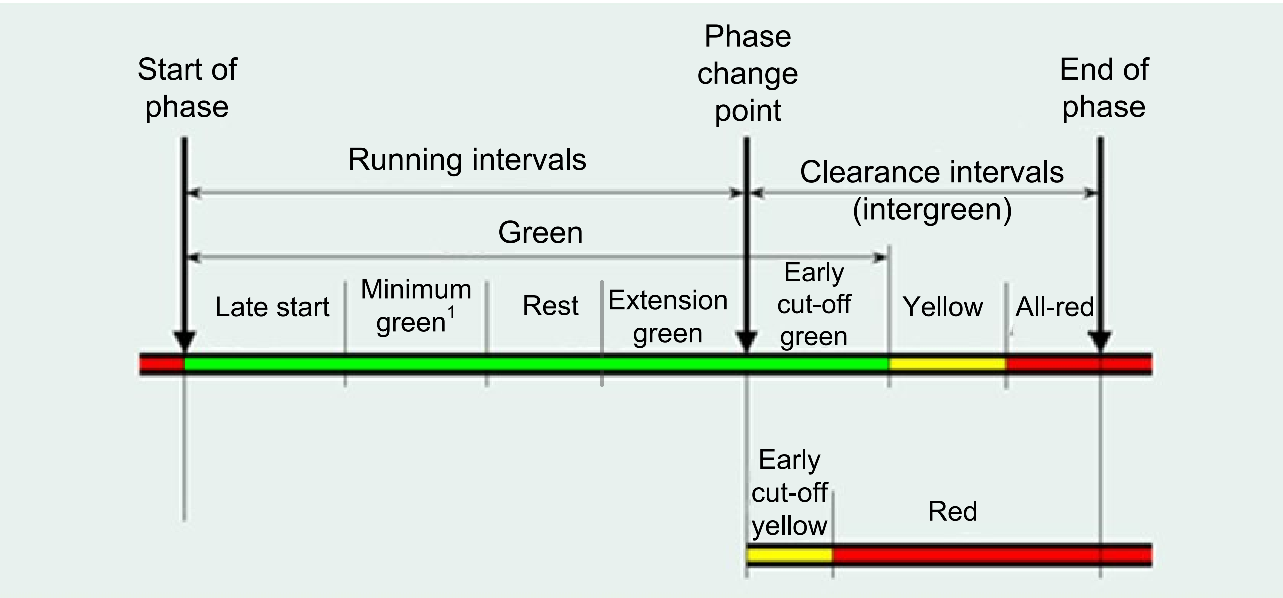
This section discusses the concepts of vehicle and pedestrian phase intervals.

Vehicle phase intervals

A phase consists of two major parts as shown in Figure 6.6, the 'running' part and the 'clearance' part. The running part of the phase is the portion between the start of the phase and the termination point. Once the termination point has been passed, the next phase has been determined and cannot be changed. The running part is divided into five sequential time periods or intervals:

- late start
- basic minimum green
- variable initial green
- rest
- extension green.

Figure 6.6: Phase intervals for vehicle traffic



1 *Minimum green includes basic minimum and variable initial green (refer to Appendix G).*

The clearance part of the phase is the portion of the phase between the termination point and the end of the phase. The clearance part is divided into three sequential time periods or intervals:

- early cut-off green
- yellow
- all-red.

The early cut-off green period allows the termination of some signal groups earlier than others. For example, at paired intersections, the upstream signals may be terminated earlier than the downstream signals in order to minimise queuing on internal approaches. The yellow period is to provide sufficient warning of the termination of the phase and allow time for vehicles to proceed if unable to stop. The all-red time provides a safe clearance time for vehicles that cross the stop line late in the yellow period. It also allows filtering traffic to clear.

The intergreen is the period of time between the termination of a green display in one phase and the beginning of a green display in the next phase. This usually corresponds with the yellow and all-red intervals.

Pedestrian phase intervals

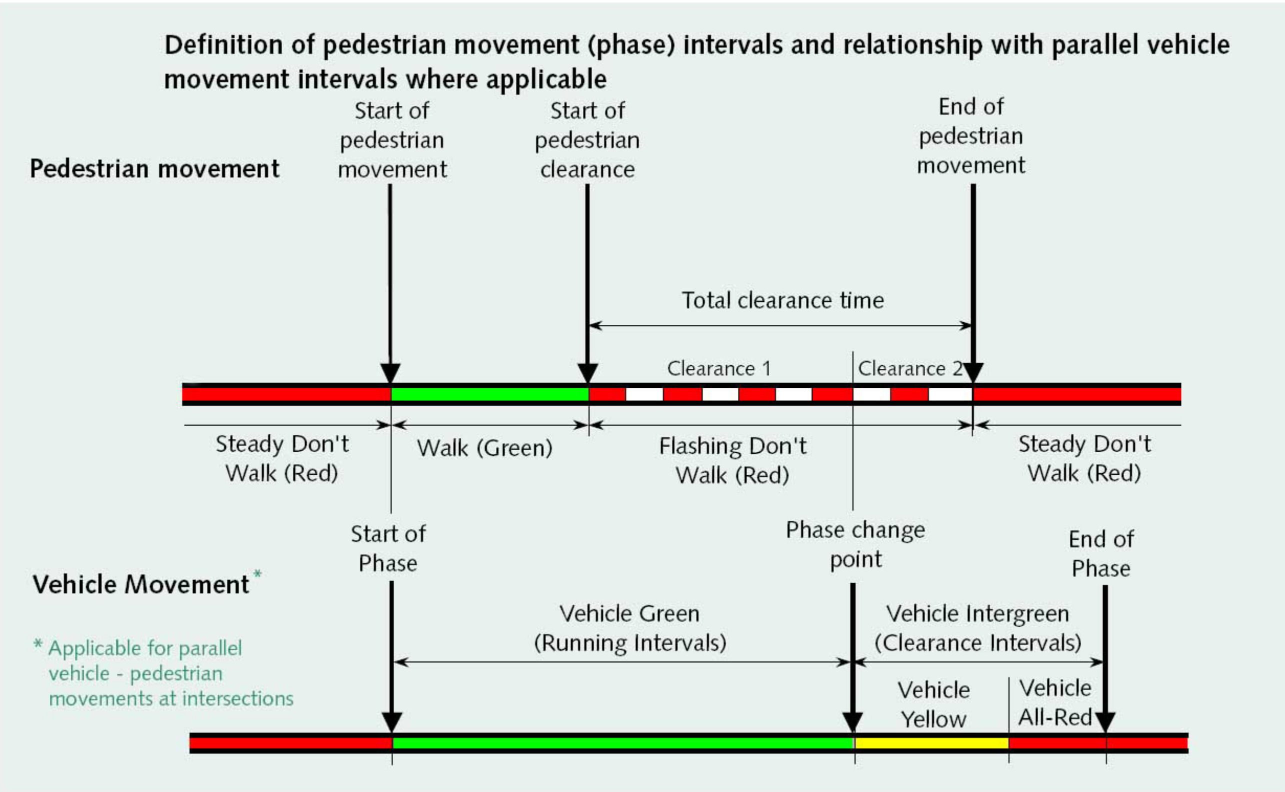
Pedestrian movements are normally grouped with vehicle movements to form a phase and run concurrently with parallel vehicle movements when appropriate. If pedestrian movements are grouped into one phase without any vehicle movements, then it is said to be an exclusive pedestrian phase. Where turning vehicles can cross a pedestrian movement, it may be necessary to provide pedestrian protection.

The pedestrian movement is divided into three sequential time intervals:

- Walk
  - Walk 1
  - Walk 2
- Clearance 1
- Clearance 2.

Figure 6.7 along with their relationship with parallel vehicle movement intervals where applicable.

Figure 6.7: Pedestrian phase intervals



Note: Where pedestrian countdown timers are used in lieu of a flashing don't walk (Red) display, a yellow countdown timer replaces the flashing red signal and displays the number of seconds left for pedestrians to cross before the red don't walk signal appears (see further discussion in a succeeding section).

The duration of the Walk display is divided into Walk 1 and Walk 2. Walk 1 is a timed interval to provide a minimum time for the display. This is intended to allow time for pedestrians to begin their crossing. Upon expiry of the Walk 1 interval, the pedestrian movement enters the untimed Walk 2 interval, where it rests until the display is terminated.

The Clearance 1 and Clearance 2 intervals provide time for the pedestrians to complete their crossing. When a pedestrian movement is introduced, the phase normally cannot terminate until the Clearance 1 interval has finished. (An exception is when the pedestrian movement is allowed to overlap.) The Clearance 2 interval can run concurrently with the phase clearance and should not be longer than the phase clearance period. The relationship between the end of the pedestrian movement and end of phase varies between jurisdictions. Some jurisdictions use a walking speed of 1.2 m/s in the calculation of clearance time and terminate the Clearance 2 interval at the end of Vehicle All Red; others adopt a walking speed of 1.5 m/s provided that the flashing don’t walk display does not overlap into the vehicle intergreen period. In practice, the timing outcomes are similar.

Because of the relatively long time that pedestrians take to cross a road, the pedestrian clearance can represent a significant amount of time which could have been used by vehicle movements in another phase. Therefore, pedestrian movements are usually introduced only by demand. An exception is in areas of high pedestrian demand, such as in the CBD during the day, where pedestrian phases may be introduced every cycle.

Pedestrian protection

Pedestrians are normally grouped with vehicle movements to form a phase (Roads and Traffic Authority NSW 2008c). This grouping should be such that the pedestrian movement run concurrently with parallel vehicle movements when appropriate. Where turning vehicles can cross a pedestrian movement, it may be necessary to provide pedestrian protection. The degree of protection can vary but can general approaches include full protection for the duration of the pedestrian movement or protection only for the initial stages of the pedestrian movement. For further details on pedestrian protection see Commentary 13.

[see Commentary 13]

Pedestrian countdown timers

Pedestrian countdown timers (PCT) can be used to help to create a more pedestrian friendly environment by giving pedestrians more information and greater awareness of their ability to cross the road (Department of Planning, Transport and Infrastructure 2013). The timers enable pedestrians at the crossing to make better decisions when crossing the road. They better inform pedestrians about how many seconds they have left to safely cross the road before the red don't walk symbol is displayed. A yellow countdown timer replaces the flashing red signal and displays the number of seconds left for pedestrians to cross before the red don’t walk signal appears (Figure 6.7). The countdown covers Clearance 1 and Clearance 2 intervals.

6.5.3 Phasing Design

Factors to consider

Phasing design is the combination of all necessary traffic movements into a plan that describes the way movements should interrelate. The choice of phasing system depends on:

- **Layout** – the number of lanes and the length of left and right turn lanes available for each movement on the approach and departure of each intersecting road.
- **Alignment** – the horizontal and vertical alignment in regard to the angle at which roads intersect and sight distance available to allow safe filtering of right turn movements.
- **Traffic flows** – the amount of traffic including proportion of heavy vehicles in each through or turning movement.
- **Signal coordination** – progression considerations for an intersection within a coordinated system.
- **Pedestrians** – which pedestrian movements need to be controlled and how they will be catered for in the phasing system.
- **Special vehicles** – whether or not buses, trams, bicycles, emergency vehicles or (rarely) trains need to be separately controlled, and how they will be catered for in the phasing system.
- **Speed environment** – the operating speed of vehicles is a factor that affects both the likelihood and severity of crashes.

Phasing designs need to take into consideration safe system principles and minimise the risk of crashes which typically result in serious injuries or death. Based on data from New Zealand and Victoria, Austroads (2017a) found that the most common fatal and serious injury (FSI) crashes at urban signalised interactions are:

- Opposing-turning (right turn against)
- Pedestrians
- Adjacent (right angle)

Phasing design should also consider safety implications of intersection signal operation during low demand periods when normal phase sequencing may not occur due to phase skipping. It is desirable to have consistency in phasing arrangements both generally and at similar intersections. This is particularly important where intersections with similar characteristics and appearance are closely spaced.

Basic elements of signal phasing

The phasing arrangement at a signalised intersection is defined by the type of phasing adopted for right turning traffic. Figure 6.8 presents definitions of basic elements of phasing alternatives that are applicable to cross or T intersections and can be adapted to intersections with more than four approaches. For clarity, movements stopped by red displays are not shown in the full phase sequence diagrams. Turning movements that give way to opposing vehicle or pedestrian movements are shown as broken lines.

Crashes involving right turning vehicles and opposing through traffic pose a significant road safety risk at signalised intersections, being the most prevalent crash type resulting in fatal and serious injuries. Accordingly, full signal control of right turn movements is preferred. Filter right turns should only be used following an assessment which demonstrates that the road safety risk is low.

A risk assessment or Safe System assessment can help determine the road safety risk. This assessment should consider exposure (i.e. traffic volume), likelihood (i.e. speed, the geometry of the turn and the available sight distance) and the likely severity of a collision (i.e. speed and impact angle). Regardless of risk, the right turn must be fully controlled (no filter) where any of the following apply:

- sight distance is restricted by opposing right turning traffic
- the right turn is across more than two lanes of opposing traffic with an 85th percentile speed greater than 50 km/h
- the right turn is across more than three lanes of opposing traffic.

Where existing sites with filter right turn movements exist outside of the above requirements, a prioritisation program should be developed to reduce road safety risks.

Crashes involving pedestrians are also a significant source of FSI crashes at urban signalised intersections (Austroads 2017a). As far as is reasonably practicable, pedestrian movements should be protected by the signal phasing. This applies particularly to conflicts between right turning vehicles and pedestrians. Options for pedestrian movements include:

- A special phase for pedestrians during which all other phases are stopped and pedestrians can walk in any direction through the intersection (‘Barnes dance’ or ‘scramble crossing’).
- Full control of vehicle movements to remove conflict with pedestrians – this is the preferred control for right turn movements.
- Partial control of vehicles movements (through a delay to the start of their movement) or allow vehicles to filter through pedestrians – subject to assessment of the risks to pedestrians through road safety audit or Safe System assessment.

- Staged crossings for pedestrians where:
  - it is not practicable for pedestrians to cross in one continuous movement
  - pedestrian crossing time would govern the phase time and overall cycle time and this would be undesirable
  - staging would provide greater flexibility in the phasing arrangements for the intersection
  - there is adequate storage in the median

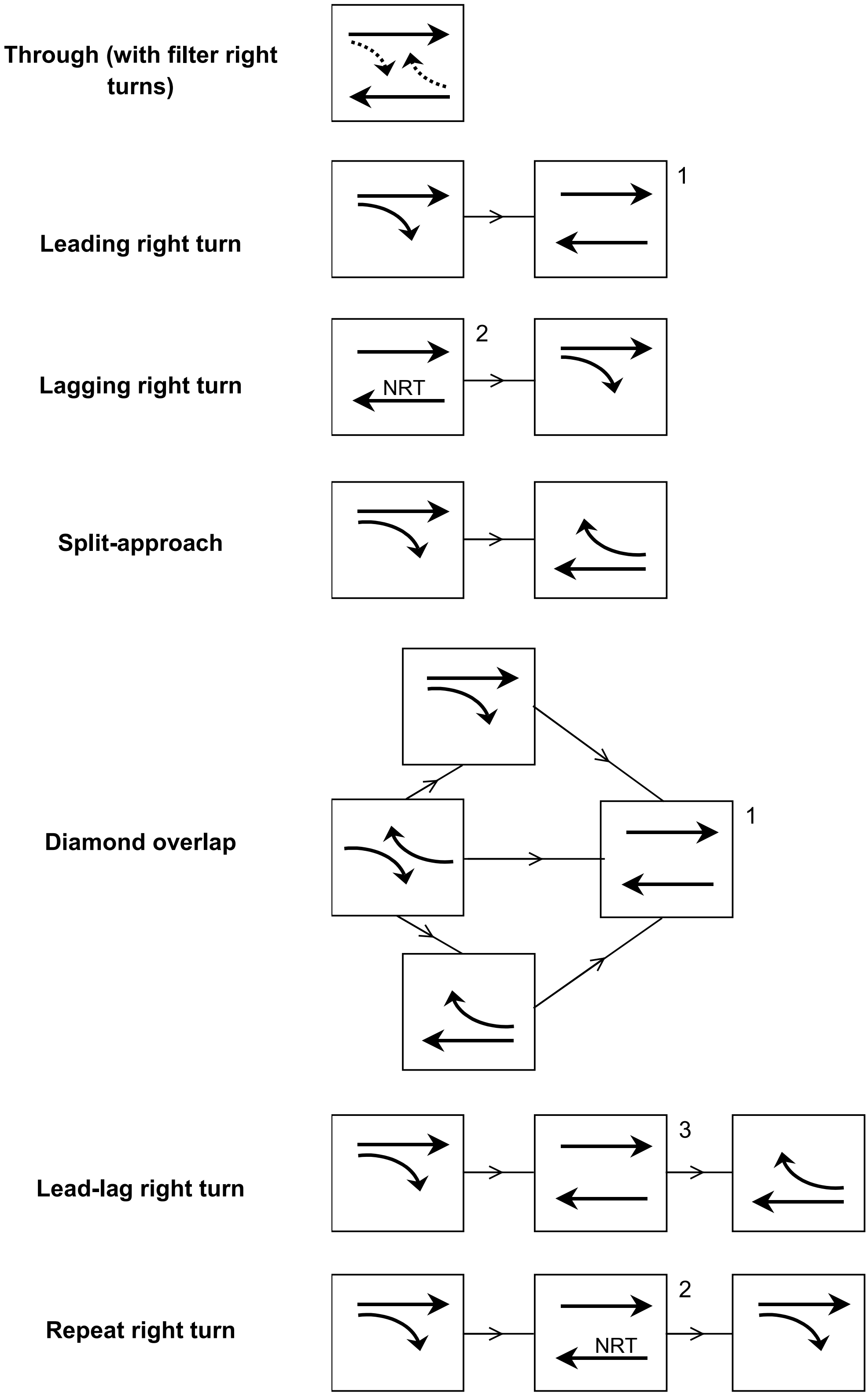
Audio-tactile traffic signals should be provided. Staged crossings should be used with care as they usually increase crossing delays and may therefore result in increased risk taking by pedestrians.

If the phasing arrangement includes phases for special vehicle types (such as public transport priority phases) they must not run in conflict with pedestrian phases.

Left turn and pedestrian movements are also not shown in Figure 6.8 for reason of clarity. Left turn movements do not control phase selection.

The basic phasing elements in Figure 6.8 show movements on one road only, say an East-West road. The leading, lagging and repeat right turn phasing options are shown in terms of the right turn movement from the west approach, but they are equally applicable to a right turn movement from the east approach. Similarly, the split-approach and the lead-lag phasing options can be in reverse order (i.e. east approach first). These phasing elements can be used to build a total phasing arrangement (i.e. a complete signal cycle) for the intersection.

Figure 6.8: Definitions of basic elements of signal phasing



1 Both filter right turns may be allowed (and either/or selection of the illustrated phases) subject to a satisfactory safety assessment.
2 Filter right turns from the approach opposite NRT may be allowed subject to a satisfactory safety assessment.
3 The leading turn must be fully controlled, and the lagging turn may be allowed to filter subject to a satisfactory safety assessment.

Notes:

NRT: No Right Turn (right turn movement must be banned where opposing through movement overlaps).

For clarity, left turn and pedestrian movements are not shown.

Crash risk factors

Safety assessment and consideration of safe system principles should be undertaken when designing the geometric layout and phasing for signalised intersections. Signalised intersections that have been designed to traditional standards are not considered to be fully Safe System compliant because collisions that occur as a consequence of road user error can result in serious injury or death. The risk of serious crashes, contributing factors and alternative designs for signalised intersections have been the subject of recent studies, including Austroads (2015 and 2017a), Turner et al (2012) and Durdin et al (2016). Findings from these studies include:

- Right turn against, adjacent direction, pedestrian and same direction (rear end and side swipe) crash types are the most prevalent FSI crashes at signalised intersections
- Crash rates increase as the number of legs increases
- Crash rates increase with an increase in speed limit
- The risk of serious right turn against crashes is generally higher if:
  - there is more than one opposing through lane
  - right turn vehicles are allowed to filter
  - signal visibility is poor
  - there are no mast arms
  - the intersection is large
  - the degree of saturation is high
- The risk of serious adjacent direction crashes is generally higher if:
  - the intersection is large and has wide approaches
  - there is a lack of right turn control
  - the signals are coordinated with an upstream intersection
  - there are no mast arms
  - there are fewer than five signal displays
- The risk of serious pedestrian crashes is generally higher if:
  - right turn movements are not fully controlled or banned
  - the intersection is large
  - the angle of skew of the intersection is more than five degrees from perpendicular
  - the signals are coordinated with an upstream intersection (applies to right turning vehicle / pedestrian crashes)
- The risk of serious rear-end rashes is generally higher if:
  - there are more approach lanes
  - split phasing is used
  - there are shared right turn / through lanes
  - the speed limit is high

For all phasing options shown in Figure 6.8 (except the split-approach phasing), providing an exclusive right turn lane is recommended in order to:

- reduce the exposure to the rear end conflict between through and right turn vehicles
- avoid lane blockage by vehicles waiting for gaps or stopped by a red display
- isolate detection of right turn vehicles to prevent through vehicles unnecessarily calling the turn phase for leading right turn phasing.

Where a right turn is banned for part of the time using a switchable electronic sign, the switching of the sign should be coordinated with the signal displays in order to obtain a safe transition. If the right turn movement is arrow controlled, the sign should preferably switch on at the same time as the arrows change from a yellow display to a red display or red arrow drop-out.

Phasing systems

The following are examples of basic phasing systems. However, phasing arrangements can be complex in many situations, including:

- large multi-legged intersections where some vehicular movements may have to be staged within the intersection
- interchange terminals where other roads are in close proximity to the ramps (e.g. side street or frontage roads)
- where special public transport (bus and/or tram) phases or emergency services phases have to be incorporated into the system.

While Figures 6.9, 6.10 and 6.11 show filter right turns, full control of right turn movements is preferred and should be the default phasing for right turns. Filter right turns may be permitted (with or without a right turn phase) following an assessment which indicates that the risk of FSI crashes is low having regard to the crash risk factors list above.

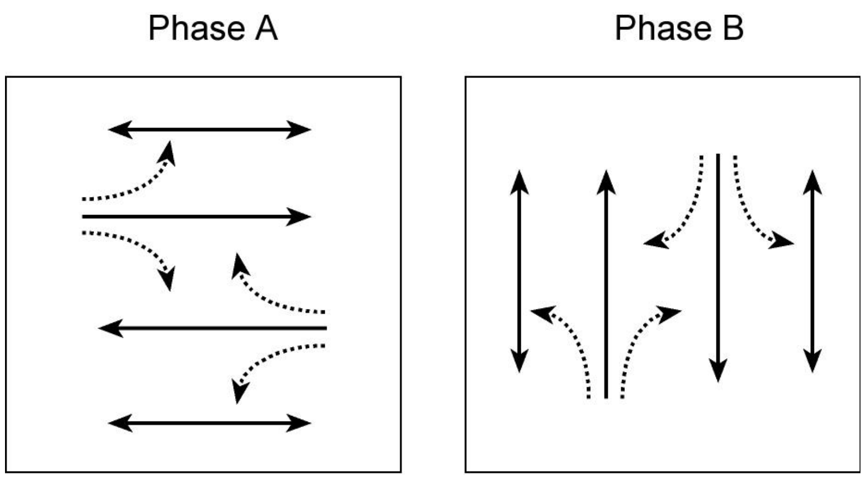
Appendix E presents an example of signal design comparing the impact of different traffic signal phasings, as well as other design changes.

Two phase system

The simplest signal phasing at an intersection involves two through phases with filter turns and parallel pedestrian movements as illustrated in Figure 6.9. For clarity, movements stopped by red displays are not shown in the full phase sequence diagrams. Turning movements that give way to opposing vehicle or pedestrian movements (filter turns) are shown in broken lines. By allocating right of way to each road alternately, the two-phase system eliminates all crossing conflicts between through traffic movements but retains 16 other conflict points (Commentary 6).

[see Commentary 6]

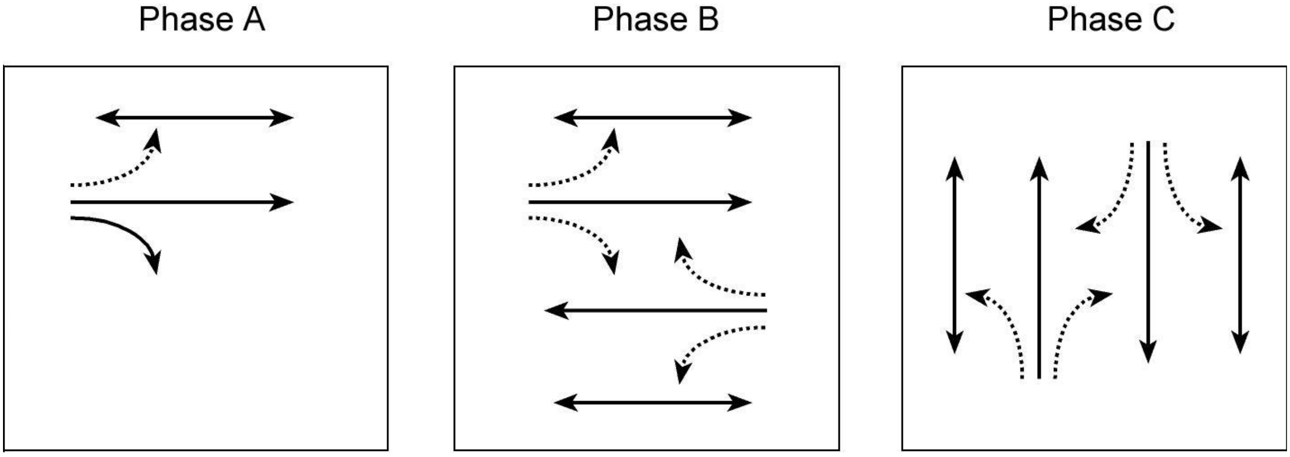
Figure 6.9: Two phase system, filter right turns and parallel pedestrian movements



Three phase system – leading right turns

Figure 6.10 shows a three phase system for a leading right turn at a cross intersection. Leading right turns are generally favoured because opposing traffic is stopped when the right turn phase starts, resulting in safer operation. Leading right turns are often provided on all intersection approaches and may run concurrently from opposing directions. The use of a leading right turn phase results in a three phase system.

Figure 6.10: Three phase system, leading right turn phasing on east-west road



Three phase system – lagging right turn

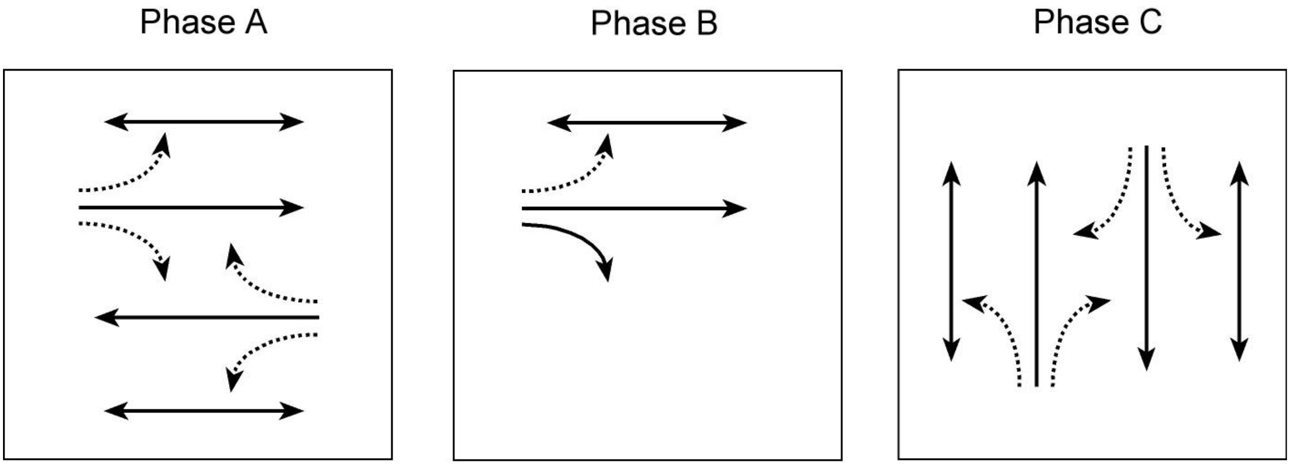
With lagging right turn phasing, a 'right turn trap' situation can occur and lead to crashes. This is because the filtering right turn vehicles would face a yellow circle display while the oncoming through traffic (from the west approach in Figure 6.11) faces a green circle display during the phase transition (from Phase A to Phase B). This situation also applies to T-intersections with filter U-turns (where permitted under local road rules).

In this case, a driver who wants to turn right by filtering at the end of the first phase from the direction opposing the lagging right turn (right turns from the east approach filtering at the end of Phase A in Figure 6.11) will see the signal display changing to yellow. The driver may think that the signals change to yellow for the opposing traffic from the west approach in Figure 6.11 at the same time, and therefore proceed and run into an opposing through vehicle for which the signal display would still be green ('right turn trap').

If the right turn movement from the direction opposing the lagging right turn cannot be banned, this conflict situation must be avoided by:

- using a leading right turn sequence (Figure 6.10)
- forcing the overlapping through movement (from the west approach in Figure 6.11 to stop and then start up again (though this is not an efficient method)
- using another phasing such as split-approach phasing, diamond overlap phasing, or lead-lag right turn phasing as shown in Figure 6.8.

Figure 6.11: Three phase system, lagging right turn phasing on east-west road



Summary of types of right turn phases

Table 6.7 provides a summary of the types of right turn phase and their characteristics. Details of the signal displays are provided in Part 10 of the Guide to Traffic Management (Austroads 2019d).

Table 6.7: Summary of types of right turn phases and their characteristics

Type of phasing	Description	Signal display	Comments
Through phasing with filter right turns	The through and left turn movements and filter right turns from opposing approaches operate in the same phase (Figure 6.8 and Figure 6.9).	Three-aspect circular (red, yellow, green) signal faces.	In general, filter right turn movements should be avoided due to the inherent risk of collisions with opposing through traffic (including motorcyclists and bicyclists) and / or pedestrians. A filter right turn (including partial filtering in conjunction with a green right turn arrow) should only be considered after: • a thorough assessment of the safety risks, and • assessment of the intersection performance If a suitable phasing alternative that can cater for the right turn movements in an efficient and safe manner cannot be found, consideration should be given to banning right turns.
Leading right turn	The right turn phase precedes the phase in which the opposing through movement runs (refer to Figure 6.8 and Figure 6.10). In Figure 6.10 the leading right turn movement from the west approach runs in Phase A, and the opposing through movement from the east approach runs in Phase B.	Three-aspect right turn arrows (red, yellow, green) in a six-aspect signal face, or two-aspect right turn arrows (yellow, green) in a five-aspect signal face.	• This is a suitable option where an arrow-controlled right turn has a filter right turn from the opposing direction), which cannot be banned and is able to filter safely and efficiently (i.e. the right turn movement from the east approach). • Where it is safe to do so, the arrow-controlled right turn can be allowed to filter through the opposing through movement during the following phase (the right turn movement from the west approach in Phase B in Figure 6.10). If filtering causes safety problems, this right turn must be stopped, using a red arrow display, when the opposing through movement is operating (full control). • Where the leading right turn movement is allowed to filter during the following phase in the case of a six-aspect signal face, the arrow-controlled turn must be terminated and held on a red arrow display at the beginning of the green circular display (at the start of Phase B in Figure 6.10). The red arrow is then extinguished for the remainder of the green circular display (red arrow drop out). • This phasing system becomes inefficient for shared lanes when a through vehicle calls the right turn phase and there are no right turn vehicles during that phase. • The provision of an exclusive right turn lane (turn-bay or full-length lane) is recommended.
Split approach	Allocates separate phases to opposing approaches at four-way intersections (Figure 6.8). The through and turning movements from each approach operate simultaneously, and right turn movements are unopposed under this phasing.	Split-approach phasing is controlled by four aspect signal faces, i.e. three circular aspects (red, yellow, green) and a green arrow aspect.	Split-approach phasing may also be appropriate where: • side streets at an intersection are slightly offset so right turns cannot make a diamond turn, or sight distance makes opposing filter right turn movements unsafe • turn proportions vary significantly during the day requiring flexible shared lane arrangements • a particularly heavy right turn movement is opposed by a very light movement, in which case the right turn vehicles may fail to give way to opposing through vehicles. Split phasing has significant safety benefits compared to signal phasing options that permit filtered right turn movements at any time during the signal cycle. However, split phasing may reduce the efficiency of site operation and can increase rear-end crashes.

Type of phasing	Description	Signal display	Comments
Diamond overlap	Allows right turns from opposing directions to operate either simultaneously or independently with the through movement on the same approach, depending on demand for the right turns and conflicting through traffic on the road controlled by the diamond overlap phasing in each signal cycle (Figure 6.8).	Diamond overlap phasing is controlled by: • three-aspect right turn arrows (red, yellow, green) in a six-aspect signal face or • two-aspect right turn arrows (yellow, green) in a five-aspect signal face.	• The diamond overlap phasing is used where opposing right turn flows are too large for efficient filter operation alone at four-way intersections, or there are safety reasons that preclude right turn filtering being allowed. • Filter right turns must only be considered after a thorough assessment of safety risks. If filter turns are used, they are introduced after both right turn movements are stopped and both through movements are started (red arrow drop out). • Filter right turns must not be used where either of the following apply: - the right turn is across more than two lanes of opposing traffic with an 85th percentile speed greater than 50 km/h - the right turn is across more than three lanes of opposing traffic • The diamond overlap phasing shown in Figure 6.8 provides leading right turns in both directions, thus avoiding phase transitions that cause lagging right turn conflict where filter turns are used. • To allow right turns to operate concurrently the swept paths of design vehicle from both approaches have to be checked to ensure sufficient clearance between vehicles
Lead-lag right turn	Combines the leading and lagging right turn arrangements, that is, a right turn phase precedes the phase in which both through movements run followed by a right turn phase for the right turn movement from the opposing approach (see Figure 6.8).	In this phasing the leading right turn must be fully controlled using three-aspect right turn arrows (red, yellow, green) in a six aspect signal face. The lagging right turn should also be fully controlled using three-aspect right turn arrows (red, yellow, green) in a six aspect signal face, or may in some circumstances be partially controlled using either three-aspect right turn arrows with red arrow drop out or two-aspect right turn arrows (yellow, green) in a five-aspect signal face.	• This phasing is useful for signal coordination purposes as right turn phases may be sequenced to optimise progression during through movement phases. • Lead-lag phasing provides less flexibility and efficiency for managing delays and queues (than diamond overlap phasing) and may not be desirable at locations where coordination is not critical. • The lagging right turn movement should be fully controlled using a red arrow to minimise the safety risk and for consistency of right turn control. Filtering of the lagging right turn should only be permitted following a thorough assessment of the safety risks. • The leading right turn movement must not be allowed to filter during the following through phase (i.e. should be fully controlled) in order to avoid the lagging right turn conflict discussed previously.

Type of phasing	Description	Signal display	Comments
Repeat right turn	Introduces the arrow-controlled right turn twice in the same cycle (see Figure 6.8) Effectively, this provides a combined leading and lagging right turn arrangement for a selected right turn movement, unlike the lead-lag right turn phasing that applies to the right turns from opposing directions.	The right turn associated with the repeat phasing should generally be fully controlled using three-aspect right turn arrows (red, yellow, green) in a six-aspect signal face. In some circumstances, partial control using either three-aspect right turn arrows (red, yellow, green) with red arrow drop out or two-aspect right turn arrows (yellow, green) in a five-aspect signal face may be acceptable. The right turn from the opposite approach to the repeat phase must be either: • banned or • fully controlled using three-aspect right turn arrows (red, yellow, green) in a six-aspect signal face.	• The right turn movement subject to the repeat phasing may be allowed to filter during the through phase (i.e. be partially controlled) after a thorough assessment of the safety risks. • The right turn movement from the opposing direction, if permitted, must not be allowed to filter during the through phase (i.e. should be fully controlled) in order to avoid the lagging right turn conflict discussed previously. • This phasing can be used for either full-time or part-time operation. Its use will depend on the degree to which right turn traffic flow fluctuates at a site. • Repeat right turn phasing increases short lane capacities by using two short green intervals (applicable to right turn bays). It is also useful where there is insufficient storage in the road into which the right turning vehicles are entering due to congestion. In this case, this phasing operates as a metering device. • The use of a repeat right turn phase introduces an additional inter-green period that may impact the efficiency of the intersection if the right turn is a critical movement.

6.6 Signal Groups

All traffic signal lanterns which have common electrical switching such that they share the same colour sequence within each phase and for each phase sequence are called a signal group. A signal group may control one movement (such as a left turn arrow controlling a left turn) or a number of movements (such as a full roundel controlling left turn, through and right turn movements).

The operation of signal groups is normally tied to phases so that certain signal groups are green in certain phases. For example, in the simple case of a four-way intersection with two phases, A and B phase will each have one signal group. If lamp monitoring is provided, A and B phase will each have two signal groups. Under more complex control, signal groups may be associated very loosely with phases or, in some cases, signal groups may even operate independently of phases.

Phase-related signal groups are identified by the phase or phases in which they are green (e.g. A, B or B/C).

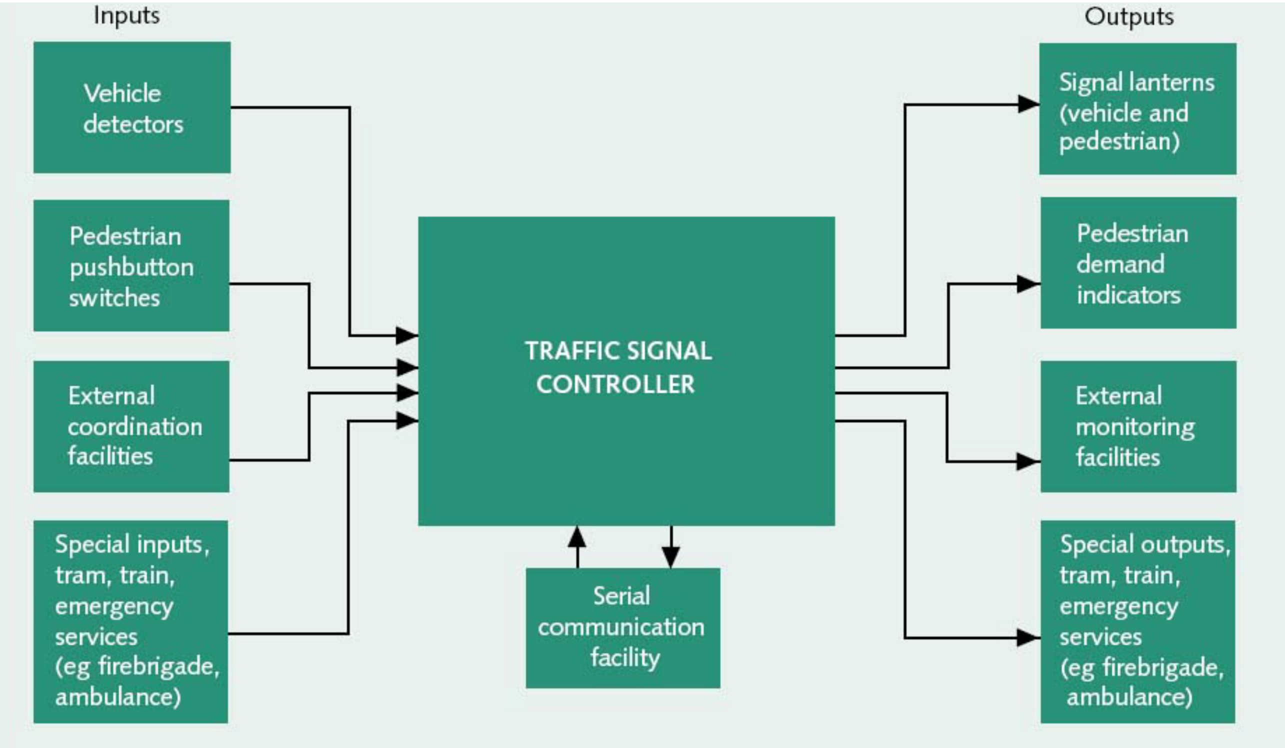
6.7 Traffic Signal Controllers

6.7.1 General

The traffic signal controller is the equipment (including the housing) that switches power to the signal lanterns and controls the duration and sequence of signal displays. This equipment is placed in a ground-mounted housing or a post-mounted housing. Further guidance on the electrical design of traffic signals is provided in Appendix F.

Figure 6.12 illustrates how the controller interfaces to the other components of the signal system. The physical characteristics of the controller are specified in AS 2578.

Figure 6.12: Typical interfacing requirements for signal controllers



6.7.2 Types of Control

Operation of a traffic signal controller depends on the type of control used. Different types of signal control for isolated (non-coordinated) intersection operation are briefly discussed in this section. For further discussion, refer to Akçelik (1995b), Gordon et al. (1996), and Roads and Traffic Authority NSW (2010c).

- **Traffic-actuated control:** Traffic-actuated control allows a variable sequence and variable duration of signal displays depending on traffic demands. This type of control is also referred to as 'fully actuated' since all movements (phases) are actuated in contrast with 'semi-actuated' control described later.
- Although fully-actuated control has been the most common type of control traditionally, the use of 'SCATS Master Isolated' control has found increased use in Australia.
- **SCATS master isolated control:** Where an intersection controller is linked to a SCATS regional computer (Lowrie 1982, 1992, 1996, 2001), it may be run under normal fully-actuated control or SCATS Master Isolated (SMI) control as alternative forms of isolated (non-coordinated) control.
- SMI control works in the same way as fully-actuated control except that maximum green times are determined by the regional computer (subject to a maximum cycle time using SCATS green split algorithms) on a cycle-by-cycle basis according to varying demand conditions. As a result of this, SMI control offers advantages over traditional fully-actuated control (Akçelik et al. 1998).
- **Semi-actuated control:** In this type of control, usually only minor movements (e.g. side road traffic) are actuated. The non-actuated phase (usually major movement) receives minimum green duration, but the green period is extended indefinitely until an actuated phase demand is received. Mid-block signalised crossings with pedestrian actuation only, i.e. where the vehicle movements are not actuated, are of this type.
- **Fixed-time control:** Fixed-time control provides only a fixed sequence and duration of signal displays. This is rarely used in Australia, because of its inefficiency and lack of flexibility.

Coordinated signal control has some elements of fixed-time operation, e.g. using a specified cycle time for all intersections in a common coordination area (Section 6.9).

6.7.3 Selection of Appropriate Control

The selection of signal control appropriate for a particular site is based upon the following criteria:

- facilities
- capacity
- operation and maintenance
- cost and availability.

6.7.4 Facilities

The various control facilities available in the signal controller determine the nature, duration and sequence of signal displays.

As the number of control facilities required increases, the controller logic becomes more complex.

6.7.5 Sequence Selection Facilities

- **Fixed sequence:** This provides for a fixed duration of signal display to be allocated to each approach cyclically. The sequence never changes, and this is the minimum sequence facility available.
- **Skipped sequence (traffic actuated):** This sequence provides for automatically altering the duration of signal displays in accordance with the measured traffic demands. Phases are designated to run in a predetermined sequence but can be skipped if there is no demand for them when it is their turn in the sequence.
- **Variable sequence:** This provides for phases to be run as soon as possible in the sequence subject to a priority of movements and termination of conflicting groups. Rather than use predetermined data, this system uses the most recently measured traffic data, fed into the system via traffic detectors. This sequence facility is available in the most recent microprocessor-based signal controllers.
- **Priority sequence:** This provides for the abrupt insertion of a phase into the sequence, e.g. in response to a train, tram or bus demand.
- **Forced sequence:** This provides for a sequence of phases to be determined by a master controller and/or external logic. This facility is required in most coordinated and other master controlled systems.

6.7.6 Display Duration Facilities

- **Fixed duration:** The duration of the display is fixed.
- **Traffic actuated:** The duration of the display is determined by the actuations of the vehicle detectors and pedestrian push-button detectors associated with that phase. This facility is available in most controllers in various degrees of complexity.
- **Traffic responsive:** The duration of the display is determined by the traffic demands on all approaches of the intersection. This facility is not yet commercially available in isolated controllers.
- **Master controlled:** The duration of the display is determined by signals/commands from a master computer or other coordination devices.

6.7.7 Coordination and Communication Facilities

These facilities are determined by the coordination requirements and/or area traffic control system such as SCATS (Lowrie 1982, 1992, 1996, 2001) within which the intersection must operate. Some possible facilities are:

- time-of-day linking (synchronous or cableless linking)
- linking by dedicated cable
- serial communication (telephone cable, radio)
- IP/internet protocol.

These facilities are discussed in detail in Section 6.9.7.

6.7.8 Controller Capacity

The controller capacity required is determined by the number of signal groups which must be switched, and the number of detector and push-button input circuits. These requirements can be determined from the intersection geometry and the phasing design. Spare capacity may be required for future expansion of the intersection phasing.

6.7.9 Controller Operation and Maintenance

When selecting a traffic signal controller, consideration should be given to the operation and maintenance requirements of each type. The staff required for these purposes must be familiar with the controller types. For new controller types or controllers installed in remote areas, consideration needs to be given to the ability of staff to operate and maintain the controllers. Arrangements may need to be made for training, operations support and spare parts for maintenance.

6.7.10 Controller Programming

The task of configuring a controller to the specific requirements of a particular site is known as adaptive engineering. Each controller has a unique program called a 'personality' which configures the controller to the specific operational design of the intersection or mid-block device it is controlling. Traffic signal controllers can also be configured to control overhead lane signals, ramp signals and signals associated with roundabouts.

Where two devices are very closely spaced, there can be advantages in using one controller for both devices, provided the controller has sufficient signal groups. This reduces installation and recurrent costs, and guarantees traffic progression (offsets) between the two devices, but increases the complexity of the personality and detection problems may be encountered if detector feeder cables are excessively long (over 100 m).

The personality specifies which signal groups run in each phase, the sequence of phases, detector functions, detector alarm conditions and default time settings. Signal groups can be controlled conditionally within a phase, e.g. in a diamond overlap phase or completely independently of the phasing, e.g. slip lane vehicle and pedestrian groups. Where there are unusual operations, such as a railway interlink, the personality logic can be quite complicated.

6.7.11 Preventing Hazardous Displays

Hazardous displays arise from failures in the mechanisms that switch power to the signal lanterns. These hazards can be minimised by interlocked switching and/or conflict monitoring.

The general principle is that if a signal group is showing green when it should not, then conflicting signal groups are forced to red, or are switched to flashing yellow.

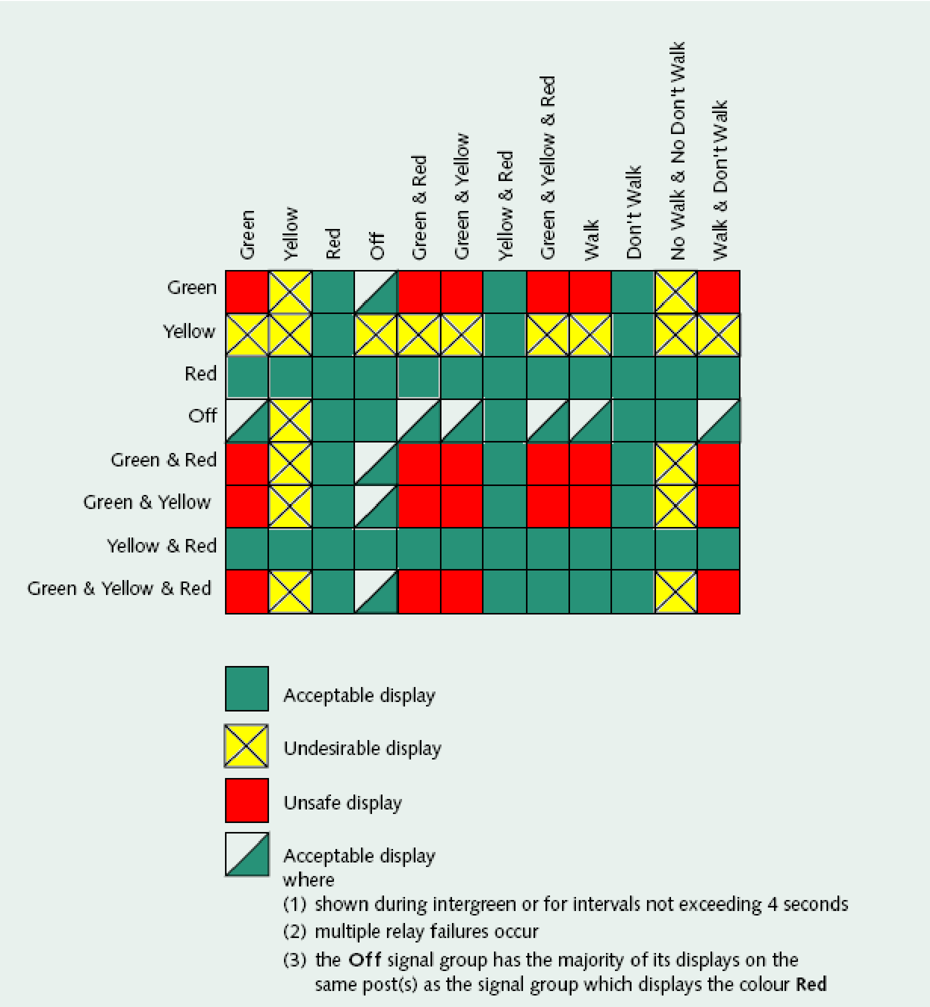
Interlocked switching is used with relay switching of lamp circuits. Switching a green to one signal group will open the circuit to conflicting green signal groups and close the circuit to the red of these signal groups.

One method of interlocking signal groups is affected by connecting relay contacts in series to create a 'chain' from the lamp active supply to the green feeds of the signal groups. When a signal group is switched to green, the green feed to signal groups lower down the chain is open circuited (green interlocking). The groups which are higher in the chain must ensure the red is displayed for groups which are lower in the chain (red interlock). Signal groups which are designed to have an off display should be in the lowest positions in the chain. They do not require a red interlock as this would override the off display.

Conflict monitoring is mandatory where solid state lamp switching is used. The circuits to the signal group colours should be monitored as closely as possible to the controller output terminals. The state of each circuit is compared with a table of conflicting signal groups specified in the personality so that unsafe displays are avoided.

A detailed study of the techniques used is beyond the scope of this Guide. Figure 6.13 indicates the acceptable, undesirable and unsafe lantern displays for conflicting movements shown on the respective axes. The adaptive engineering required is equipment dependent.

Figure 6.13: Safety of signal displays



6.7.12 Signal Controller Timing Settings

There are two major aspects of traffic signal timing:

- The determination of maximum cycle times and green times for each phase (sometimes called green splits). Determination of these is part of the design process for traffic signals.
- The determination of controller time settings. These are the more detailed settings that:
  - ensure the safe operation of traffic at the signals, including yellow, all-red and pedestrian clearance timings
  - for traffic-actuated signals, determine the behaviour of the signals under varying traffic conditions when maximum cycle times and green splits are not required.

These are discussed in this section. Appendix E presents a worked example of signal design which includes guidance on determining maximum cycle times and green times.

Table 6.8 provides a summary of the various signal timing purposes and settings required for safety and to minimise delay. Discussion of the basis for each setting and how they can be determined within the range given here is quite detailed and is therefore presented in Appendix G. Table 6.8 also provides a directory to the relevant section of Appendix G for each setting.

Accurate records of the time settings at traffic signals are essential. Remember, they may be called in legal proceedings. It is also important for records of time settings used in the past to be retained. Appendix E includes an example of a signal timing record card, a copy of which is usually kept in the controller housing for reference by visiting field staff.

Table 6.8: Summary of signal controller settings

Setting	Purpose	Typical range	Appendix G reference
Maximum cycle time	Limit the total cycle time to reduce delays and queue lengths where applicable	80–100 seconds (simple two-phase) 130–160 seconds (complex phasing)	Appendix G.2.1
Late start	Allow the introduction of some signal groups to be delayed for a preset time	0–6 seconds	Table G 1 Appendix G.4.1
Basic minimum green	Ensure that the green signal is displayed for a safe minimum time	4–10 seconds	Table G 1 Appendix G.4.2
Increment (for advance detectors)	Add a small amount of time to the Basic Minimum Green Setting to provide extra green time for vehicles stored between the detector and the stop line	0.5–2.0 seconds	Appendix G.4.2
Maximum variable initial green (for advance detectors)	Limit the initial green period determined by increments	Depends on the distance of advance detectors from stop line	Appendix G.4.2
Maximum extension green (or maximum green)	Control the maximum extension green time (after minimum green intervals) available to each phase or signal group	Choose for optimum traffic performance under different traffic conditions; avoid unduly long cycle times	Table G 1 Appendix G.4.3
Gap	Set the maximum allowable time period between successive detector actuations before the movement terminates ('gaps out')	1.0–4.0 seconds	Table G 1 Appendix G.4.4
Early cut-off green	Allow the termination of some signal groups earlier than others	0–10 seconds	Table G 1 Appendix G.4.5
Yellow time	To provide sufficient warning of the termination of the phase	3–6 seconds	Table G 1 Appendix G.4.6
All-red time	Provide a safe clearance for vehicles that cross the stop line towards the end of the yellow interval	1–3 seconds	Table G 1 Appendix G.4.6
Presence	Set the period for which a detector must be occupied before a demand is recorded	0–5 seconds	Table G 1 Appendix G.4.7
Headway (space)	Set the desirable space time between successive detector actuations for efficient traffic flow	0.3–1.5 seconds	Table G 1 Appendix G.4.7
Waste	Set the value of the sum of the excess of the actual space time over the space time setting at which the phase is terminated	4–12 seconds	Table G 1 Appendix G.4.7
Minimum red arrow time	To allow appropriate red arrow display time considering driver reaction/perception characteristics	2–5 seconds	Appendix G.4.7
Pedestrian walk time	Set the duration of the green Walk display	5–16 seconds	Table G 1 Appendix G.5.1
Pedestrian clearance time	Set the duration of the flashing don't walk display	6–20 seconds	Table G 1 Appendix G.5.2
Pedestrian delay	Provide a delay between the start of a phase and the start of the Walk display	0–10 seconds	Appendix G.5.4

6.8 Traffic Detection

An important aspect of traffic-responsive signal control systems is the detection of vehicle and pedestrian traffic demands in order to determine the signal displays required, their initiation and duration. For this purpose, detectors are used to register the presence and/or passage of vehicles and pedestrians.

Detectors can be grouped broadly as vehicle detectors, push-button (pedestrian) detectors and special detectors. Many types of detectors exist including inductive loop, push-button, microwave/radar, infrared, sonic, video image processing, magnetic and pressure. The most common detectors are inductive loop detectors for vehicles and push-button detectors for pedestrians. Commentary 7 discusses the construction of inductive loop detectors. For additional information on detectors, refer to Klein (2006) and Klein et al. (2006).

[see Commentary 7]

For a traffic-actuated system to be effective, it must obtain information on the traffic conditions in the controlled area and the approaches to it and must be capable of providing the following information on a lane-by-lane basis:

- whether there are vehicles and pedestrians waiting against a red signal
- whether filter movements are filtering freely
- whether free-running movements need an extension of green time
- movements of special vehicle types.

These requirements can be met by:

- using a suitable type of detector
- choosing the correct dimensions for the detection zone
- locating the detector correctly in respect to the stop line or where pedestrians will be waiting
- correctly interpreting the data from the detector.

Detectors must have a clearly defined detection zone so that interference from adjacent lanes is low. Currently, the best type of vehicle detector that meets the detection requirements for Australian and New Zealand traffic control systems is the inductive loop detector. Although there are other types of detectors that satisfy these requirements, they are generally operationally or economically inferior in normal situations, and are not considered further in this section.

Abnormal situations or temporary detection requirements during roadworks or situations of road surface instability may be satisfied by use of microwave detector units and video image processing has found increased use in recent years. These detectors are increasingly being used for the detection of pedestrians.

6.8.1 Traffic Detection During a Signal Cycle

Traffic can be detected at any time during the signal cycle. In this respect, there are two considerations:

- **Initial detection:** Arriving traffic (vehicle or pedestrian) faced by a red signal registers an initial demand (via a detection system) that it requires a green signal.
- **Subsequent detection:** Vehicle traffic approaching on a green signal registers (via the same detection system) that it requires the green signal to continue.

The type and location of detection systems used determine the parameters of the initial and subsequent detections, and as a consequence the design and operation of traffic responsive signal control are determined.

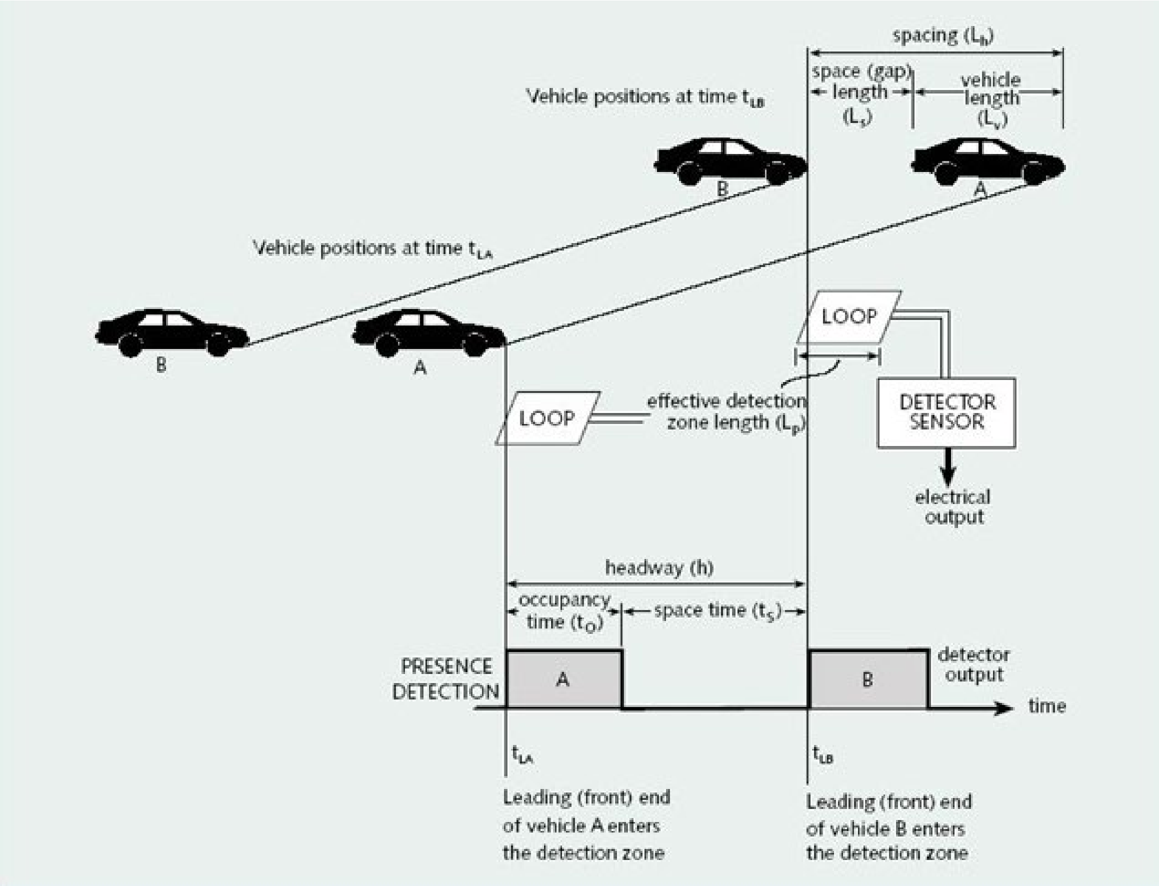
6.8.2 Vehicle Detection Modes

The sensor units allow the detector to be operated in one of two modes:

- **Presence mode:** The sensor unit produces a continuous output whenever a vehicle is in the detection zone. The duration of the output (occupancy time) depends on the length and speed of the vehicle. Both moving and stationary vehicles can be detected.
- **Passage mode:** The sensor unit produces a brief pulse when a vehicle enters the detection zone, thus detecting only moving vehicles regardless of their length or speed. Passage detection does not provide further pulses if stationary (or very slow moving or closely spaced) traffic occupies the detection zone.

Figure 6.14 illustrates the information that can be gained from the modes of operation of a loop detector in presence detection mode. This includes spacing (distance), headway (time), occupancy time, space (or gap) time and distance, vehicle length, as well as the fundamental traffic parameters of speed, flow rate and density, which are not shown in the figure. Relationships between the basic traffic parameters and their use in traffic signal operations can be found in the Guide to Traffic Management Part 3 (Austroads 2017c). For more detailed guidance, refer to Akçelik, Besley and Roper (1999).

Figure 6.14: Basic traffic parameters of a vehicle loop detection system



Passage detection can only allow a measure of headway time and the flow rate. Presence detection on the other hand can indicate not only the continuing presence of a vehicle, but also allows the determination of occupancy and space times (as well as parameters such as the SCATS DS (degree of saturation). Commentary 8 describes the formulation of SCATS DS and its role in SCATS control systems.

[see Commentary 8]

It is for reasons associated with the ability of a loop detector in presence mode to determine the spacing and headway parameters that it is the preferred detection technology for traffic signal control.

6.8.3 Detection System Functions

Vehicle detectors provide the following functions on a lane-by-lane or approach basis.

Demands for a phase

Detectors initiate a demand for a phase, i.e. 'call' a phase. This is usually done for vehicles waiting against a red signal. The demand can be a 'locking call' in which case the call is only cancelled when the requested phase runs. The location of detectors for locking calls requires that only vehicles serviced by the demand phase be detected. Presence or passage detection mode can be used.

The demand can be a non-locking call, in which case the call is cancelled when the detector input is removed. Non-locking calls are used for approaches or lanes where the vehicle may leave the approach before the called phase occurs, for example:

- a right turn phase is no longer needed when right turn vehicles filter before the turn phase is displayed
- a side-street phase is no longer required if the waiting vehicle turns left when a left turn green arrow display occurs in the preceding phase (e.g. a three-phase T-intersection case with overlap left turn and right turn movements)
- where left turn on red is permitted.

Non-locking calls can be achieved by presence detection only. The detector loops must be located so that the vehicle waiting for the called phase is detected.

Conditional demands

In some situations, a conditional demand is required to detect stopped or slow-moving traffic. A call is not registered until the detector is occupied for a minimum set time ('presence time'). The call may be locking or non-locking. Presence detection mode is required for conditional demands, and the length and location of the sensor loops are critical for this purpose.

Green extension

Detectors are used to extend green displays when there is a continuous stream of approaching vehicles. The most common way of extending the green period is to compare vehicle space times with a preset 'gap setting' (Appendix G).

Strategic functions

For traffic signals operating under wide area control systems (Section 6.9), some detectors have a dual role:

- **Tactical:** to determine the demand and/or duration of phases in the same way as isolated traffic signals.
- **Strategic:** to provide information in order to enable computation of cycle length, phase splits and signal offsets for system control.

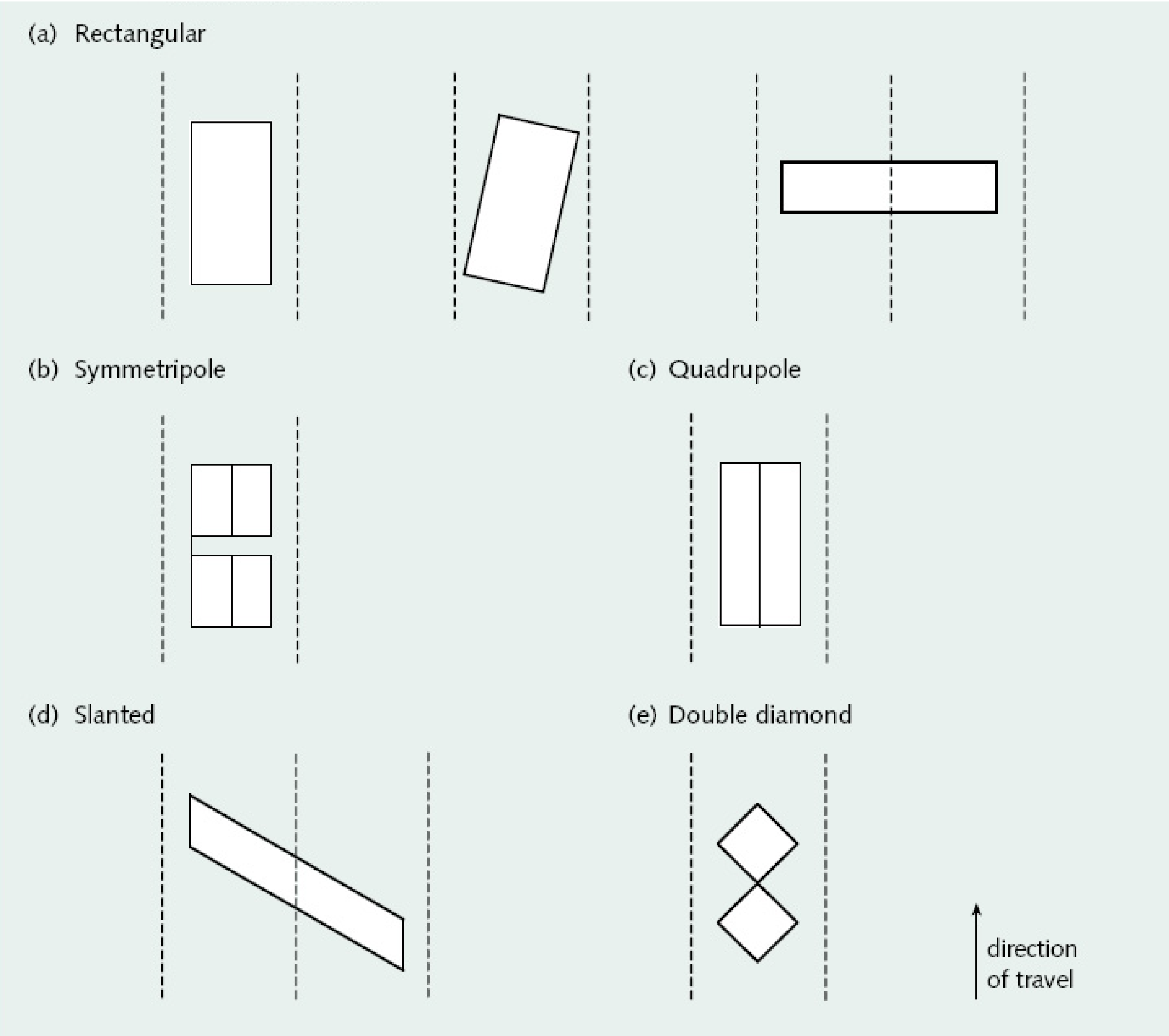
6.8.4 Loop Shape and Size

Loop size, which determines the detection zone, is dependent on two factors:

- **Longitudinal response:** This is determined by the detection zone required along the roadway. The length depends upon the detection function required, and normally varies between 1 metre and 12 metres.
- **Transverse response:** This is determined by the transverse width of the detection zone required across the roadway. The width depends upon the dimension of the target vehicles to be detected and the width of the traffic lanes. The accuracy of target vehicle detection, in relation to the detection function required, also affects the loop width chosen.

Figure 6.15 shows different loop shapes, namely (a) rectangular, (b) symmetripole, (c) quadrupole, (d) slanted and (e) double diamond. Figure 6.15(a) shows various applications of the rectangular loop, including its use in a single lane and across several lanes, as well as a loop swung at an angle of approximately 20 degrees to the direction of vehicular travel, which has been found to be effective in detecting cyclists (this application can also be used for symmetripole and quadrupole loops).

Figure 6.15: Typical loop shapes



Hulscher and Sims (1974) examined the relative merits of the various configurations with respect to sensitivity, noise immunity, interference and similar performance parameters. The most common loop shape in use is symmetripole but some jurisdictions use a rectangular loop shape.

From electromagnetic considerations, the optimum loop size for presence detectors are the vehicle dimensions. However, as vehicles vary in size a compromise is necessary. To adequately detect small vehicles, a loop size of 10 square metres is considered a practical maximum.

The sensitivity of detection within and between lanes is also determined by the shape and size of the loop. Length of the detection zone is not necessarily the same as the loop length due to fringing field effects (as affected by the sensitivity settings of the detector).

The efficiency of the detection system is maximised by providing one loop per lane. The dimensions and placement of loops affect performance and are discussed in the following sections.

6.8.5 Location of Detectors

The location of the loop affects the functions that the detector is able to perform. The types of vehicle loop detectors used for traffic signal control include:

- stop-line detection
- advance detection
- queue detection.

Based on a study of traffic signal control practice in Australia (Akçelik 1995a) as well as more recent experience:

- The setback distance for stop-line detectors is generally 1.5 m but ranges from 0.3 m to 2.5 m.
- The detector loop length used for stop-line detection is generally 4.0 m or 4.5 m, however recent research indicates that a shorter loop length could be appropriate, especially for right turn lanes (Akçelik, Besley & Roper 1999).
- In Queensland, loop lengths in the range 1.2 to 3.0 m have been used, and the current practice is 2.0 m loops at setback distances of 35–45 m for major roads and 6.0 m for minor roads.

6.8.6 Stop-line Loop Detection

A detection system that employs stop-line presence detection on a lane-by-lane basis is the most common method used in Australia. This has been a result of the development of the SCATS wide-area traffic control system (Lowrie 1982, 1992, 1996, 2001).

Stop-line loops require greater sensitivity as slow-moving or stopped vehicles must be detected. The location of the loop in relation to the stop line must ensure that the normal stopping position of the first vehicle is in the detection zone.

Figure 6.16 shows location and layout of 4.5 m and 11 m loops, and loop configuration. The lateral dimension of the loop should be derived from Table 6.9 for each situation as indicated in Figure 6.16.

The 11 m detector may be used at locations where a shared or exclusive right turn lane permits filtering and a right turn phase is also provided (Figure 6.16). In practice, the 11 m detector is split into two 4.5 m sections (designated approach and departure loops) that act together in some conditions and separately in others. The longitudinal position of an 11 m detector may vary depending upon intersection geometry.

Figure 6.16: Layout of stop-line loop

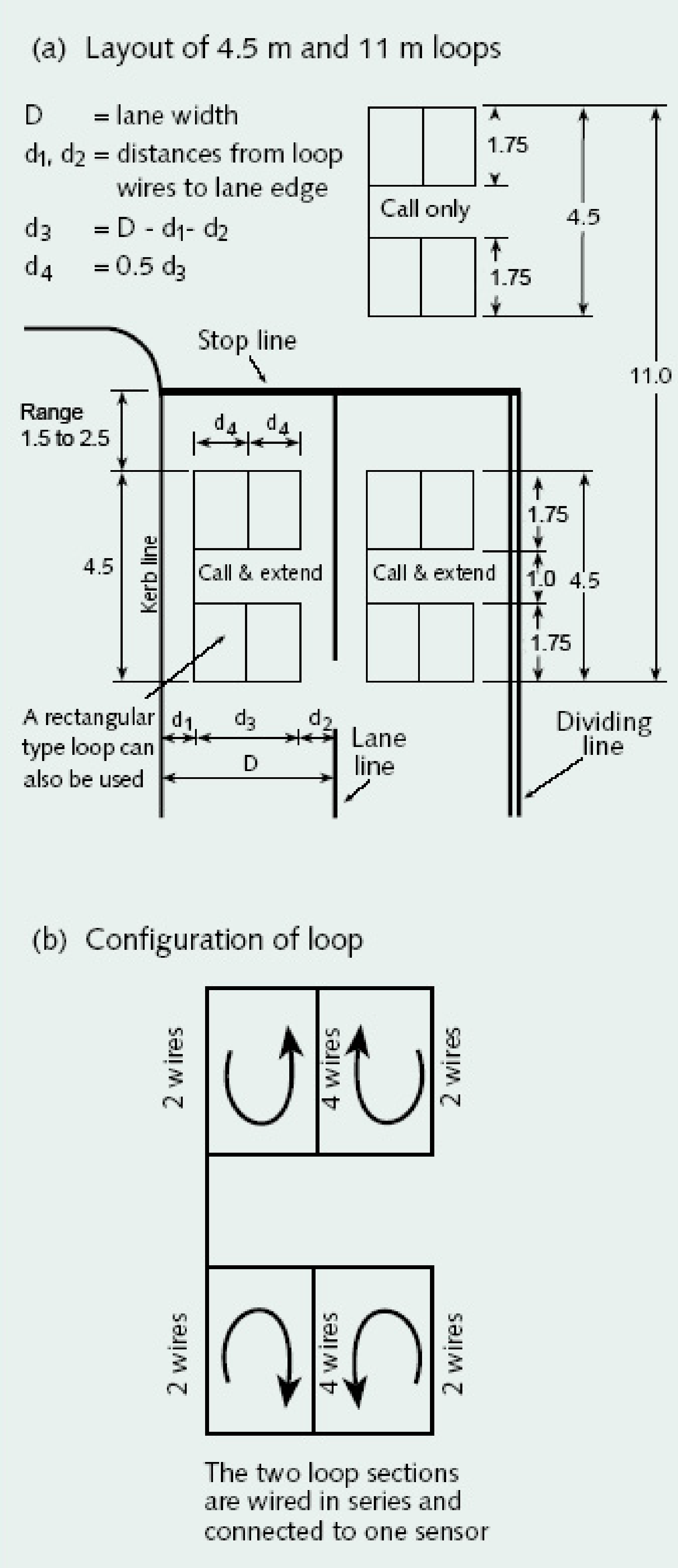


Table 6.9: Lateral dimensions of symmetripole loops

Spacing from each outer wire of loop to lane edge			
Lane width (m)	General (m)	When adjoining	
		Median strip (m)	Kerb side (m)
2.5–3.0	0.74	0.55	0.83
3.0–3.5	0.73	0.54	0.82
3.5–4.0	0.72	0.53	0.81
4.0–4.5	0.71	0.52	0.80
4.5–5.0	0.70	0.51	0.79
5.0–5.5	0.69	0.50	0.78

Note: d1 and d2 in Figure 6.16.

The transverse spacing in Table 6.9 between the outer conductor of the loop and the lane boundary has been chosen to minimise:

- unwanted detection of vehicles in the adjacent lane (over-counting)
- the number of undetected vehicles (especially two-wheeled vehicles) which do not travel through the loop's zone of influence (undercounting)
- the consequences of missing a vehicle (such as a two-wheeled vehicle) and therefore not servicing that vehicle with a green light.

The optimum spacing between detectors in adjacent lanes is theoretically achieved when over-counting errors are equal to undercounting errors. A spacing of 1.4 m has been found to provide a good compromise.

The gap between the two sections comprising each 4.5 m loop must be kept to a minimum to give good longitudinal response for all classes of vehicle. However, the smaller this gap, the more the overall sensitivity is reduced. In practice, the dimensions in Figure 6.16 represent a good compromise between the various factors.

6.8.7 Advance Detection

In Australia, detectors located in advance of the stop-line for the purpose of detecting moving vehicles (passage detection) are usually used on safety grounds, (i.e. at sites where approach speed is high and particularly when there is a large proportion of heavy vehicles). For this purpose, they should be located to suit the stopping distance required for the 85th percentile approach speed, where possible.

Advance detection can also be used to provide signal priority for buses and trams.

For additional guidance on the use of advance detection, refer to Commentary 9.

[see Commentary 9]

6.8.8 Queue Detection

Presence detectors, in conjunction with a presence timer, may be used to detect queues of excessive length. A 'presence time' is set (e.g. five seconds) and when the loop is occupied for longer than this set time, a demand is registered.

Applications of queue detection include:

- registering a demand for a right turn phase by determining if the queue is too long to filter adequately
- detecting critical storage conditions that require the cessation or introduction of certain phases, for example
  - traffic blocking the middle of a major intersection
  - queues on freeway exit ramps that are likely to overflow onto the freeway
  - queues on or near a railway level crossing
- use at roundabout metering signals to create gaps for roundabout legs with excessive queuing where the main approach contributing to the circulating stream causing the queuing problem ('metered approach') is stopped by a red signal when the queue reaches the advance queue loop on the 'controlling approach'
- use at part-time metering signals at sign-controlled intersections to create gaps in major road traffic to reduce excessive delays experienced by vehicles on the sign-controlled approach by stopping the major road traffic using a queue detector on the sign-controlled approach.

Note, however, that stop-line presence detectors do not detect the length of a queue. Some video detection systems are able to measure queue length, but their high cost inhibits their use at non-critical locations.

6.8.9 Pedestrian Detection

Push-button detectors are the most common detectors for pedestrians. To register a demand, a pedestrian must actuate the appropriate pedestrian push-button. When the button has been pressed an illuminated panel (pedestrian indicator), when present, may be used to indicate to the pedestrian that the demand has been recorded by the controller. The illuminated panel switches off when the demand is satisfied.

Audio-tactile push-buttons should be used where needed by visually-impaired or elderly pedestrians (Hulscher 1976).

Additional detectors in the footpath or overhead (usually infrared or microwave) may be used to detect the presence of pedestrians on the crossing and to modify the duration of the walk or clearance (flashing don't walk) intervals (e.g. puffin crossings).

In addition to push-button detection, controllers may also be set to register a fixed demand for any pedestrian movement so that the movement runs each cycle. This should only be considered where the pedestrian volumes are high and the cycle time is long enough to accommodate all phases with pedestrian movements. Examples include CBD areas during the busy times of day. Automatic introduction may be invoked by time-of-day, or on the condition that the coordinated signal cycle time exceeds a certain value.

Information concerning push-button location is contained in Appendix H.

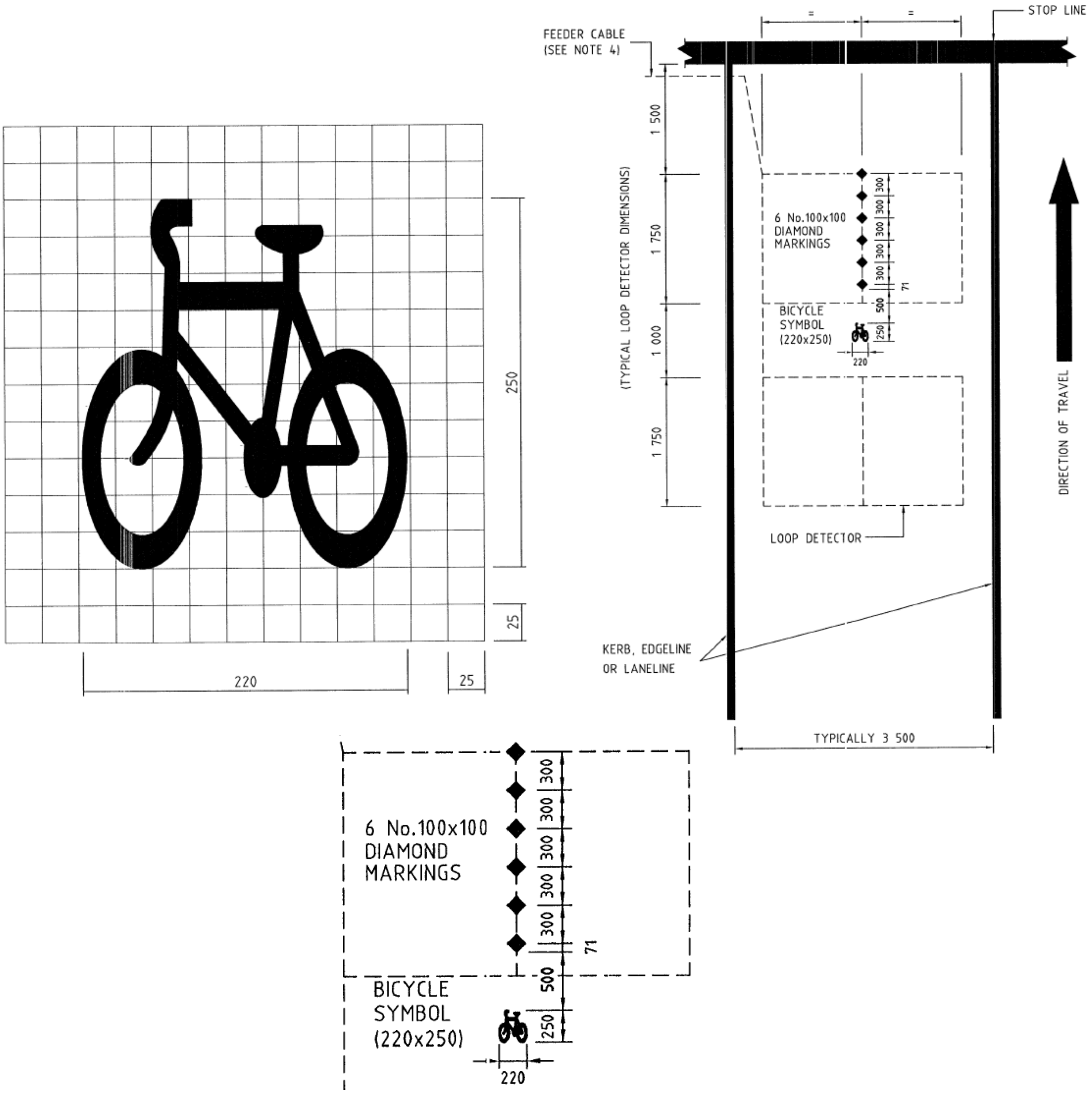
6.8.10 Bicycle Detection

When separate bicycle lanes are provided and bicycle detection is required, loop detectors with very sensitive loop arrangements spanning the whole width of the bicycle lane are necessary. An evaluation of inductive loops for bicycle detection has been reported by Leschinski (1994).

Where bicycle traffic shares lanes with other vehicles, it is not always possible to detect bicycles due to their small electromagnetic footprint. It might be appropriate in such cases to install other devices such as push-buttons to assist bicycle riders to lodge a demand or pavement markings to indicate the most bicycle-sensitive area of the detection zone, or, where bicycle volumes are low, do nothing.

To improve detection of bicycles, detectors can be marked to indicate the most bicycle-sensitive zone, as shown in Figure 6.17.

Figure 6.17: Pavement markings for bicycle detection at traffic signals



Notes:

Dimensions: measurements in mm.

Colours: white.

Feeder cable details have not been shown. This drawing is for bicycle loop detection pavement marking details only.

Source: Main Roads Western Australia (2016).

6.8.11 Bus Detection

Normal loop detectors may be used for bus detection where ‘bus only’ lanes are provided. Where buses share lanes with other traffic, one technique used involves an ‘on-bus transponder/transmitter’ which is a device fitted to the bus. This identifies the presence of a bus to a roadway sensor. In some applications, a bus is detected only when such a device is actuated by the driver.

Other techniques may be used which utilise:

- combinations of detectors which either identify the bus by its length or its height above the road surface
- classification detectors which identify the bus by special loop detectors.

6.8.12 Tram Detection

Three methods of tram detection are currently in use:

- Loops: Trams in a dedicated lane may be detected by inductive loops placed between the rails. They may produce passage or presence actuations.
- Transponder/transmitter systems: In a mixed traffic lane, inductive loops do not uniquely identify trams. Transponder or transmitter systems as described above for buses can be used.
- Skates: Skates are overhead contacts in the energy supply lines to the tram. As the tram pickup passes, a momentary isolated contact closure is transmitted to the controller. These perform a locked call function only. This method of detection is now rarely used.

6.8.13 Emergency Vehicle Detection

Emergency vehicles can be selectively detected:

- Through a transponder/transmitter fitted to the vehicle:
  - when emergency vehicle demands are recorded by a controller, existing displays are terminated safely and a special priority traffic phase is introduced and maintained until the demand is removed.
- By push-buttons:
  - typical applications involve signals in close proximity to fire stations and ambulance depots. The emergency service may require a green movement of fixed duration within a fixed time of the demand being made, or they may be prepared to wait for the required movement and move off when indicated by the control equipment.

For further guidance on emergency vehicle priority systems, refer to Section 6.16.

6.8.14 Railway Traffic Detection

Where railway level crossing signals are coordinated with road traffic signals, detection is necessary in order to:

- register the presence of vehicle queues on or near a level crossing
- detect an approaching train in sufficient time to terminate traffic signal running phases and complete any necessary clearance phases to dissipate the risk posed by vehicle queues.

Queue detection (Section 6.8.8) is used to identify the presence of vehicle queues near a crossing. This may be required to ensure that:

- queues generated by a traffic signal will not extend across railway tracks
- queues resulting from level crossing operation will not interfere with traffic movements at the road intersection.

In order to detect an approaching train, it is necessary to interlink road traffic signals with railway level crossing controls. This is discussed in Section 6.12.5.

6.9 Coordination of Traffic Signals

6.9.1 Introduction

Coordination of traffic signals is implemented to improve the level of service of a road or a network of roads where the spacing of signals is such that isolated operation causes frequent stopping and unnecessary delays to platoons of vehicles formed at upstream signals. Signal coordination also helps to prevent queues at a downstream intersection from extending back and reducing the capacity of an upstream intersection, particularly where there is limited queue storage space between intersections.

Signal coordination is accomplished essentially by:

- operating all signals in the area on the same system cycle time
- maintaining a time (offset) relationship between start or end times of green displays at adjacent (upstream and downstream) signals according to the speed of vehicle platoons so as to obtain a progression of green periods along the road.

6.9.2 Objectives of Signal Coordination

The design objective in determining a signal coordination plan (the system cycle time, durations of green displays, and offsets) is to optimise a selected performance measure (e.g. minimise delay or the number of stops or a combination of delay and stops). The performance measure can be applied for the area as a whole, or for selected routes in the area (e.g. major arterial roads).

Signal coordination is an important tool for achieving other key traffic management and environmental objectives, such as improving the level of service of arterial roads to reduce the pressure on residential streets and central business district (CBD) areas, and reducing fuel consumption and pollutant emissions.

The benefits of traffic signal coordination include:

- reduction in travel time and delay
- reduction in the number of stops
- improved capacity of closely-spaced signalised intersections
- reduction of noise levels, air pollution and energy (fuel) consumption
- achievement of other area or corridor traffic management goals
- increased capacity of the road network which may avoid or defer expensive road widening.

Reduction in intersection crashes is often cited as a benefit of signal coordination. However, research into the safety benefits of signal coordination is limited. Ma et al (2016) estimated crash modification factors for adaptive traffic signal control (ATSC) in Virginia USA. The study concluded that ATSC can have a statistically significant effect on reducing total crashes at urban signalised intersections. The estimated crash modification factor (CMF) was 0.83. However, fatal and injury crashes did not change by a statistically significant amount.

Turner et al (2012) conducted research into key geometric, traffic and operational features of traffic signals and their effect on specific crash type, including right angle, right turn against, rear-end and pedestrian–vehicle crashes. The research objectives were to develop:

- crash prediction models for traffic signals in New Zealand
- a safety toolkit that could be used by transport engineers to predict the expected number of crashes at new and upgraded traffic signal sites.

The study analysed crash data from five New Zealand cities and Melbourne, Australia. It found that the presence of signal coordination increased the risk of right angle crashes and pedestrians being struck by right turning vehicles. However, the effect was not uniform across all cities. In Melbourne and Auckland, signal coordination was found to decrease the risk of right angle crashes. The study did not include any conclusions regarding the net safety effect of traffic signal coordination.

Usually, delay, number of stops, or a combination of delay and stops are used as the performance measure. It is generally recognised that the following factors favour minimising stops:

- fuel consumption, exhaust pollution and operating cost – these are increased by stop-start driving cycles, therefore reduced if fewer vehicles are stopped
- driver expectation – drivers relate coordination more to the number of stops than to overall delay.

Minimising the number of stops, fuel consumption, emissions or operating cost does not yield the same signal timing plans as the minimum delay criterion due to the different offset and cycle time requirements. However, such longer cycle times do not involve a significant delay penalty.

On the other hand, long cycle times result in longer delays to side-road traffic and pedestrians, and result in longer queue lengths. In areas such as CBD networks where queue storage spaces are limited, long cycle times may lead to the blockage of upstream signal stop lines (queue spill back), and the resulting loss in the network capacity leads to increased delays and stops.

6.9.3 The Case for Coordination

An isolated intersection is one in which vehicle arrivals at each approach are not significantly affected by other intersections. This situation can be managed by traffic actuated controllers with a high degree of efficiency.

The presence of an upstream signalised intersection or mid-block signalised crossing alters the arrival pattern from random to platooned flow. This enables improved traffic flow to be achieved if the green display is arranged to coincide with the arrival of the platoon.

The closer the traffic control signals are spaced, the more platooned (less random) the arrival patterns become, and the greater the opportunities are for improved efficiency afforded by coordination. Generally, benefits result from coordination when traffic signals are provided at successive intersections spaced less than one kilometre apart. At spacings of less than 500 metres, the reductions in delays and stops usually exceed 20% (Bastable 1980). Most studies of installed coordination systems, both fixed-time and adaptive, have shown the systems to be highly cost-effective. The benefits of adaptive systems are further discussed in Section 6.10.

6.9.4 Design Considerations

While detailed aspects of the design process for coordination of traffic signals are quite specific to the control system chosen, the following factors shown in Table 6.10 should be taken into account.

Table 6.10: Design considerations for coordination of traffic signals

Factor	Design considerations
Traffic management policies	The strategies for the routes and networks to be coordinated should be determined, including public transport considerations (Part 4 of the Guide) (Austroads 2016a).
Roadway factors	Information is required on the capacities of roads both at and between intersections to enable an assessment of the manner in which traffic platoons will behave. The effective capacity of the coordinated system is determined by the capacities of critical intersections that must be identified. Data on the geometry of the intersections in the network, including the location of existing and planned intersections and signalised crossings, and the distances between the stop lines are required.
Geometric factors	Examination of intersection and roadway geometry may indicate the need for changes to improve the flow of traffic. Examples of geometric improvements include the provision of exclusive right turn lanes, left turn slip lanes, and line-marking alterations to minimise lane changing caused by the lack of lane continuity along a road.
Traffic factors	A complete inventory of traffic movements along a route to be coordinated is required to enable progression charts (time-distance diagrams) and signal timing plans to be prepared. Each individual intersection must be assessed first, after which appropriate combinations of intersections may be assessed on a coordinated basis using a common cycle time.
Traffic equipment	An inventory of existing equipment is necessary to identify constraints imposed by this equipment and to determine required changes.

It is also important that the design process for traffic signals at an intersection not be done in isolation from consideration of the effects of coordination, either immediately on completion or in the future. Commentary 10 provides a summary of these considerations.

[see Commentary 10]

6.9.5 Principles of Coordination

There are three fundamental control parameters in preparing a signal coordination plan:

- a common system cycle time (one half of the cycle time in the case of double cycling)
- green splits
- offsets.

In addition to these parameters, alternative signal phase sequences should be considered to achieve improved signal coordination.

A system cycle time can be selected by first determining an appropriate cycle time for each intersection in the area, e.g. using the practical cycle time method (Akçelik 1981, Miller 1968, Webster & Cobbe 1966). Then, the intersection with the largest cycle time can be designated as the critical intersection, and its cycle time can be used as the common system cycle time.

Some minor intersections in the area can be operated with a cycle time of half the system cycle time (double cycling) when it is found that this can reduce delay to side-road traffic and pedestrians significantly without unduly increasing the number of stops on the main road.

Alternatively, coordination areas can be re-arranged to achieve a better grouping of the intersections with similar cycle times as far as the network geometry permits. For an overall benefit to be derived from signal coordination, the benefit from progressions must exceed the dis-benefit from the operation of some intersections at a higher than optimum cycle time. Wherever possible, measures should be taken to decrease the cycle time requirement of the critical intersection so as to improve the performance of traffic not only at the critical intersection but also in the control area as a whole.

Since all intersections in the area are to operate with the common system cycle time, the green splits for each intersection are calculated using this cycle time (except in the case of double cycling).

An **offset** is the difference between the beginning (or end) times of the green periods at the given intersection and a selected ‘reference intersection’, i.e. it is the time difference between phase introductions (or terminations). Accordingly, offsets can take positive or negative values. For example, in Figure 6.18(a) Intersection 1 is the reference intersection (offset, $O_1 = 0$), and Intersections 2, 3 and 4 have positive offset values (O_2, O_3, $O_4 > 0$). In Figure 6.18(b) and (c), Intersection 3 is the reference intersection (offset, $O_3 = 0$), Intersection 4 has a positive offset value ($O_4 > 0$) and Intersections 1 and 2 have negative offset values (O_1, $O_2 < 0$). The reference intersection is used for offset calculation only, and is not necessarily the critical intersection.

Ideally, offsets should minimise the need for a platoon to vary its progression speed and should maximise the number of vehicles arriving at the downstream signal during the green period considering all vehicle movements. However, offsets are usually selected to obtain good progression for major movements. Basic strategies for determining offsets are discussed below.

6.9.6 Offset Strategies

There are four basic offset strategies for coordination along a route. These are:

- coordination of starting offsets (i.e. the beginning of green periods at all signals)
- coordination of finishing offsets (i.e. the end of green periods)
- simultaneous offsets (i.e. the green periods start at the same time)
- maximum bandwidth (i.e. maximise the amount of green time available to a platoon along a route).

The offset is determined by:

- the distance between signals
- the progression speed along the section of road between signals
- the sources and flow rates of vehicle platoons entering from the upstream intersection
- flows entering and exiting mid-block
- platoon dispersion characteristics
- the queue of vehicles waiting at the downstream signal.

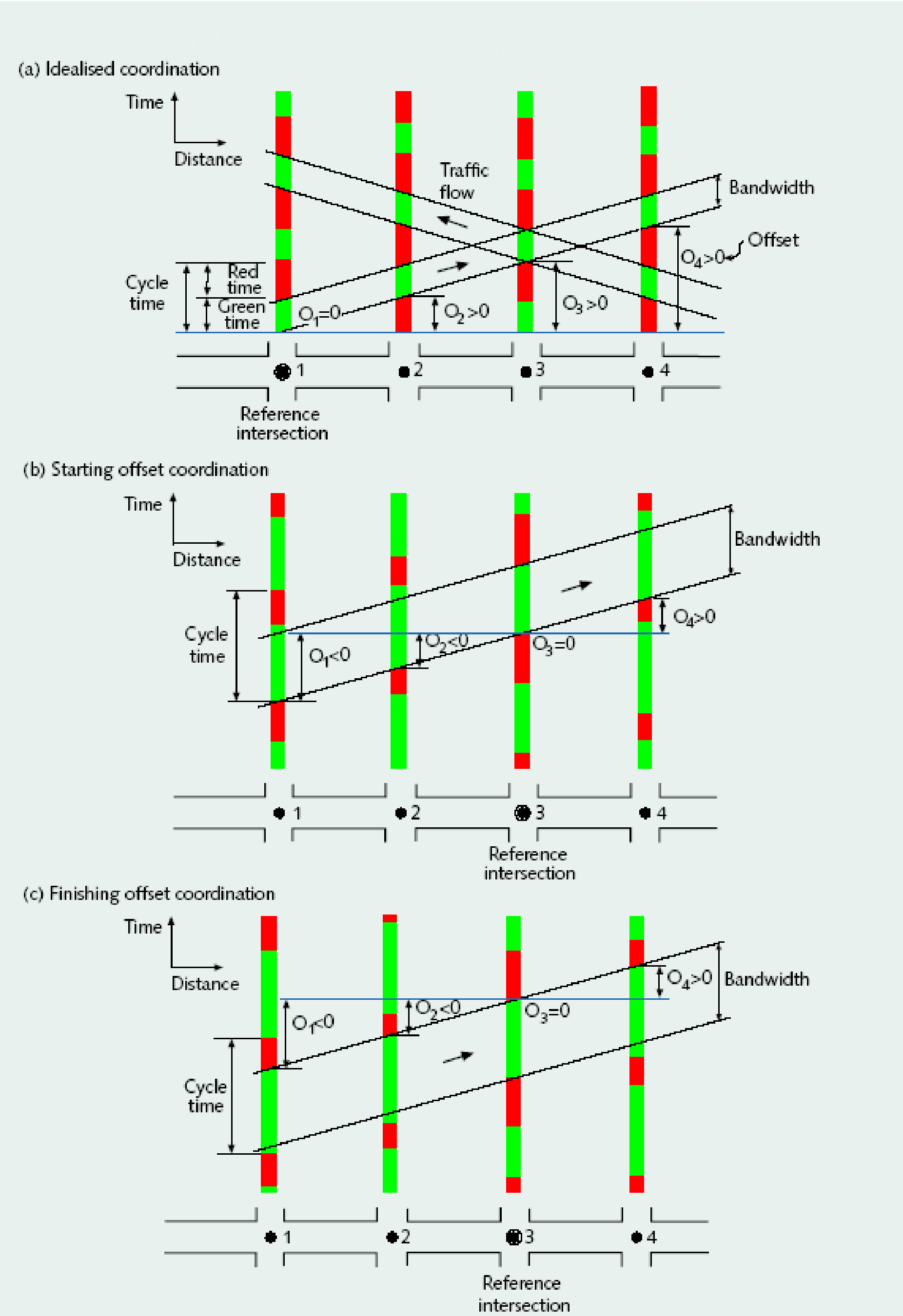
Figure 6.18(a) shows a time-distance diagram for an idealised situation where the green times on the arterial approaches of all intersections are equal and good progression is provided in both directions. Unequal green times and different spacing between intersections make it difficult to achieve coordination in both directions of a route or on all directions in a network.

Figure 6.18(b) and Figure 6.18(c) illustrate the starting offset and finishing offset strategies for one-way progressions, respectively. In these cases, the value of offset equals the average travel time based on the design (progression) speed.

The aim of a starting offset strategy is to provide minimum stops. The lead vehicles are presented with green signals before they reach each intersection in order to achieve smooth progression. There may be, however, a penalty for vehicles towards the rear of the platoon. At those intersections where less green time is available to the through phase, all vehicles may not have cleared the intersection before the phase is terminated. Consequently, the trailing vehicles will be stopped forming residual queues. These vehicles must then wait until the next cycle and experience delays, and may also interfere with the progression of the platoon from the next cycle.

By coordinating finishing offsets, minimum delay can be achieved since few vehicles travelling on the arterial route will be caught within the system. The disadvantage of this technique is that vehicles may encounter queues or red signals at those intersections where green time is limited. Although the delay before the through phase can be introduced may be short, the smoothness of the progression is disrupted. At some intersections, this may cause all vehicles to stop and the back of the queue to extend back towards the upstream intersection. As a general rule, it is more acceptable to coordinate starting offsets.

Figure 6.18: Strategies for determining offsets for coordinated signals



A compromise between the starting and finishing offset strategies is often possible (e.g. synchronisation of the mid-points of green periods as discussed in Akçelik (1981), but as a general rule, it is more acceptable to coordinate starting offsets.

The simultaneous offset strategy is useful when intersections are closely spaced, and residual queues at the downstream intersection can cause blocking of the upstream intersection (Rouphail & Akçelik 1992).

The bandwidth is the amount of green time common to all signals along the route. As shown in Figure 6.18(a) to (c), the bandwidth can be determined as the maximum time interval which can be drawn on a time-distance diagram between two parallel lines, with a slope corresponding to the design progression speed, enclosing the green periods of all the signals in the system. Though simplistic, the bandwidth gives an indication of the ability of the signals to pass a platoon of vehicles through the system without stopping.

It is necessary to construct different signal coordination plans in order to cater for differing traffic flow (demand) patterns, i.e. am peak, pm peak and off-peak. Each plan consists of the system cycle time, green splits and offsets. The plans are selected either by time-of-day or by using a traffic-responsive method, or calculated on-line by adaptive control algorithms (see types of coordination in Section 6.9.7).

The basic offset strategies discussed above do not involve modelling of queues that are likely to exist at downstream signals as a result of the trailing end of the main road platoon being stopped in the previous signal cycle and vehicles turning from the side roads of the upstream intersection. These queues interfere with the progression of platoons. Furthermore, the calculation of signal coordination plans that yield optimum progressions is not an easy task especially for closed-loop network formations, i.e. two-way progressions on an arterial road and grid networks. For this reason, various computer methods have been developed for determining optimum signal offset plans.

Signal timing plans should be verified by on-site observations, and fine-tuned accordingly. See Coordination Timing Criteria (Section 6.9.9) for further discussion.

6.9.7 Types of Coordination

There are numerous options available for signal coordination. These options fall into three basic categories in terms of hardware architecture (Lowrie 1996, 2001):

- local interlinking (cable)
- synchronous (cableless) linking
- wide area control systems.

Local interlinking: these systems comprise a small number of closely spaced signals, interconnected by a cable which allows the operation of one signal to affect the operation of the others. In such systems, usually one of the signal controllers assumes the role of master and may contain a number of timing plans to suit traffic conditions at different times.

An intersection signal controller with a nearby midblock signalised crossing controller can be coordinated via local interlinking. In this case, the intersection controller imposes restraint periods on the pedestrian signal controller during which the introduction of the pedestrian phase is inhibited.

A variety of local interlinking systems have been used in the past. They have now been replaced by wide area control systems.

Synchronous linking: The synchronous (or cableless) linking system can be applied to a large system of signals without relying on a central computer (e.g. the SCATS Flexilink mode of operation as discussed later). Coordination of signals is achieved by reference to an accurate clock in each signal controller. These clocks are initially set to exactly the same time and synchronised by reference to the mains supply frequency.

Each controller contains one or more signal timing plans and a weekly schedule for the introduction of the plans according to the time-of-day and day of the week. The timing plans include the cycle time and green splits to be used and, because the clocks are synchronised, the cycle position of each controller can be synchronised. This allows offsets to be specified and maintained. Synchronous linking uses a fixed cycle time but allows local vehicle actuation of minor phases within the constraints of the timing plan.

Although they provide a low-cost solution, cableless linking systems pose serious problems in maintaining the clocks in synchronism, even in cities with reliable mains power. However, synchronisation of the signal controller clocks can be maintained using a ‘dial-in dial-out’ system. This system can be programmed to call each site in a linking system at regular intervals to synchronise the signal controller clock. The dial-in dial-out system can also be used to modify linking data as well as monitor on-site operation.

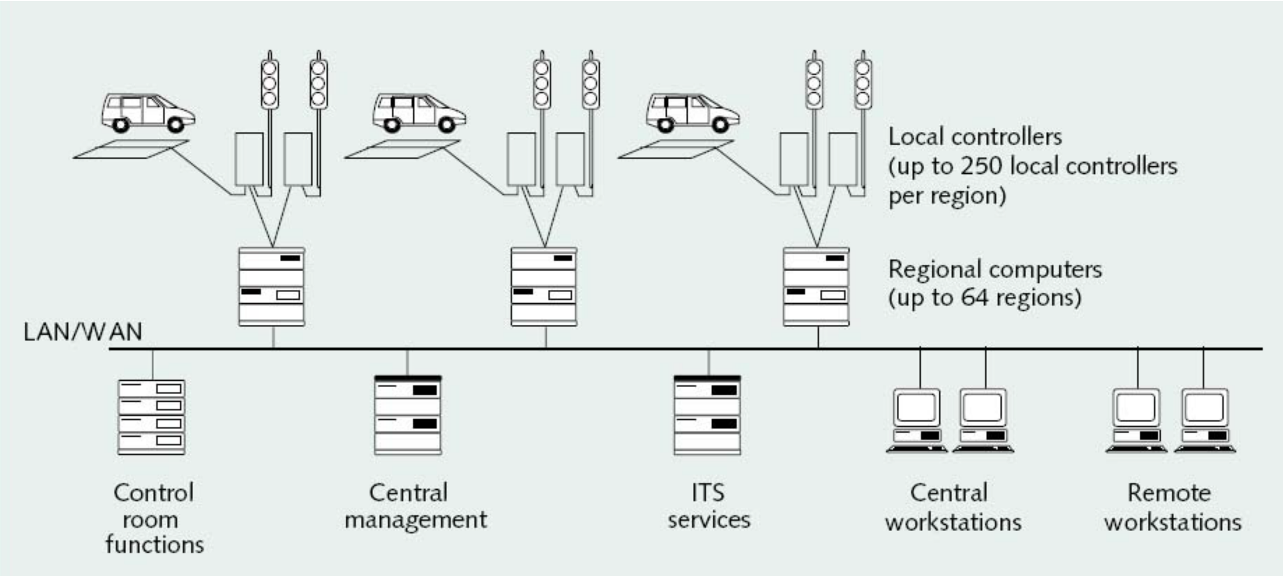
Synchronous linking is the fall-back mode of operation in some wide area control systems for use when the central control computer fails.

Wide area control systems: Wide area control systems, usually known as area traffic control (ATC) or urban traffic control (UTC) systems, involve one or more centrally or regionally located computers controlling relatively large numbers of signals. These systems provide for centralised monitoring and control, and often include a traffic control centre which is staffed for significant periods of the day to monitor operations and assist with relief of congested traffic conditions which result from traffic incidents and signal equipment malfunctions.

All signals in centrally controlled systems are connected to the traffic control computers, usually by leased data lines or, in some cases, by dedicated cable systems.

In Australia and New Zealand, SCATS is widely deployed (Lowrie 1982, 1992, 1996, 2001; Charles 2001) except in Queensland where the STREAMS system is also in use. The SCATS system is used in many cities around the world. Typical system architecture used in the PC-based SCATS 6 system is shown in Figure 6.19. For a detailed description of the SCATS system, refer to Lowrie (1996).

Figure 6.19: SCATS 6 PC-based wide area control system architecture



6.9.8 Coordination Methods

Traffic control systems to implement signal coordination can be categorised as follows according to the operating method (control philosophy) employed:

- fixed-time plan selection system
- traffic-responsive plan selection system
- fully-adaptive system.

Fixed-time plan selection system

In fixed-time control systems, predetermined signal timing plans are introduced according to a weekly schedule or timetable. Each plan defines the cycle time, green splits and offsets to be used for the duration of the plan. Depending on the complexity and variation of traffic demand patterns, between three and ten plans are usually provided, typically for the morning and evening peak periods, business hours, late night traffic and weekends. Signal timing plans are calculated offline using manual or computerised methods.

Fixed-time control does not rely on data from vehicle detectors although some variants include a degree of local traffic actuation that requires the use of detectors. Fixed-time systems offer the advantage of relative simplicity of both equipment and control philosophy. On the other hand, they are unable to cope with unpredicted traffic conditions. Furthermore, as traffic conditions change in time, signal plans become inappropriate (aged). This requires collection and processing of large amounts of data for updating of signal timing plans. Deferral of the development of new timing plans or introduction of ad hoc changes to the plans and timetables result in sub-optimal traffic performance.

Traffic-responsive plan selection system

This system selects predetermined signal timing plans using algorithms that respond to changing traffic conditions based on data collected from detectors.

The simplest form of traffic responsive operation is based on pattern matching. In this method, plan introduction times are modified or selected by comparison of measured traffic parameters (usually flow and/or occupancy) with predetermined levels of these parameters. Typically, these parameters are derived from data measured on a limited number of detectors located so as to capture predominant characteristics of known traffic conditions.

This mode of operation offers flexibility in plan introduction times, but suffers from most of the problems of fixed-time systems and cannot allow for unpredicted demand patterns in a satisfactory way.

Fully-adaptive system

Fully traffic-responsive control employs a large number of vehicle detectors, usually at every controlled signal. Two such systems that have been widely accepted are SCOOT (Hunt et al. 1981) and SCATS (e.g. Lowrie 1996, 2001).

The adaptive mode of operation of SCATS is known as Masterlink. SCATS also provides for a fall-back cableless linking mode known as Flexilink, which is used to maintain a level of signal coordination in the event of failure of the regional computer or parts of the communication system.

A fully-adaptive system generates appropriate signal timing plans on-line in a continuously variable fashion using the extensive traffic flow and density data provided by vehicle detectors. As a result, signal timing plans can suit a wide variety of traffic conditions, responding to wide variations in demand pattern and changes in network capacity caused by incidents and other factors such as roadworks.

Fully-adaptive control systems require expertise to set up and review if optimal performance is to be maintained. The flexibility of the system is dependent on a large number of detectors. The cost of installing and maintaining these detectors is high compared to lower performing fixed-time systems.

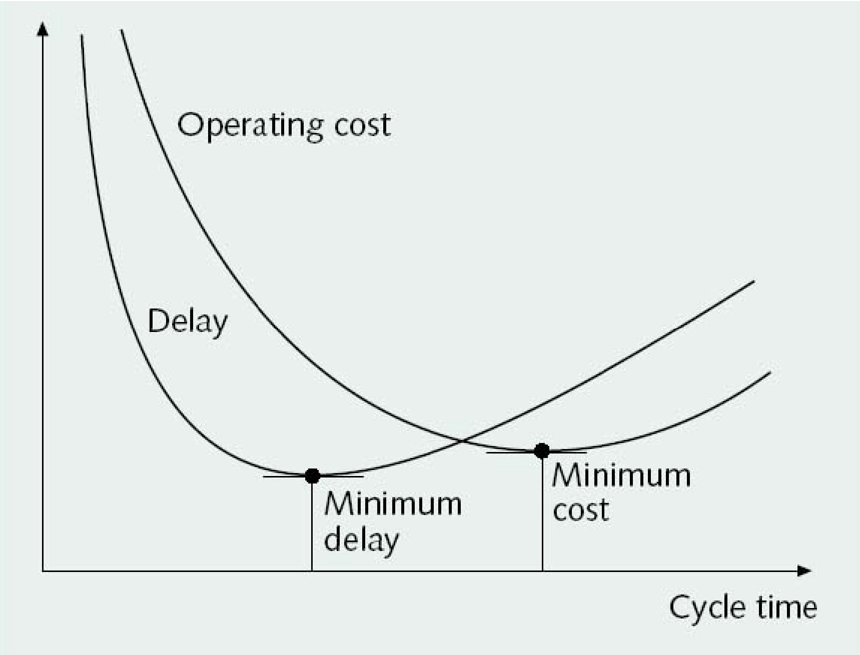
6.9.9 Coordination Timing Criteria

The principal objective of coordination timing is to optimise a selected performance measure. Usually, delay, number of stops or a combination of delay and stops are used as the performance measure. It is generally recognised that the following factors favour minimising stops:

- crash risk – this is greatest at the change of signal phases, and is reduced if fewer vehicles are stopped
- fuel consumption, exhaust pollution and operating cost – these are increased by stop-start driving cycles, therefore reduced if fewer vehicles are stopped
- driver expectation – drivers relate coordination more to the number of stops than to overall delay.

Minimising the number of stops, fuel consumption, emissions or operating cost does not yield the same signal timing plans as the minimum delay criterion due to the different offset and cycle time requirements. However, as shown in Figure 6.20, such longer cycle times do not involve a significant delay penalty.

Figure 6.20: Relationship between traffic performance and cycle length for coordinated signals



On the other hand, long cycle times result in longer delays to side-road traffic and pedestrians, and result in longer queue lengths. In areas such as CBD networks where queue storage spaces are limited, long cycle times may lead to the blockage of upstream signal stop lines (queue spill back), and the resulting loss in the network capacity leads to increased delays and stops.

6.9.10 Developing Signal Coordination Plans

Signal coordination plans can be prepared manually using time-distance diagrams, or off-line optimisation software, e.g. TRANSYT (Li 1988, TRL 2011, McTrans 2011) and LinSig (JCT Consultancy n.d.). Preparation of signal coordination plans are also relevant to fully-adaptive control systems, e.g. offset plans for the Masterlink mode and timing plans for the synchronous linking Flexilink fall-back mode in SCATS.

It is also possible to test signal coordination plans in a virtual environment via a microsimulation traffic model of the area under consideration interfaced to the signal control system. The technique is described in Millar et al. (2004). However, building a traffic model can be a resource intensive process that will rarely be warranted for this alone. The technique is more likely to be feasible where the traffic model has already been built for other purposes.

Austroads (2010a and 2010b) provides guidance on selecting appropriate modelling techniques that may assist in identifying options for aiding signal coordination plan development or traffic signal timing optimisation.

6.10 Benefits of Adaptive Traffic Signal Control

There are clear benefits to be had from coordinating the operation of traffic signals across groups of intersections and there are several options available to achieve this. The options fall into three basic categories in terms of hardware architecture:

- local interlinking (cable)
- synchronous (cableless) linking
- wide area control systems.

Traffic control systems to implement signal coordination can be categorised according to the operating method (control philosophy) employed:

- fixed-time plan selection system
- traffic-responsive plan selection system
- fully-adaptive system.

Fixed-time traffic signals are rarely used in Australia and New Zealand, as wide area, adaptive traffic control systems have been successfully deployed.

The benefits of traffic signal coordination include:

- reduction in travel time and delay
- reduction in the number of stops
- improved capacity of closely-spaced signalised intersections
- reduction in intersection crashes
- reduction of noise levels, air pollution and energy (fuel) consumption
- achievement of other area or corridor traffic management goals
- benefits from the increased capacity of the road network which helps to avoid expensive road widening projects.

The benefits of adaptive traffic control (ATC) over fixed-time control have been the subject of several studies. The scale of benefit is quite specific to the characteristics of the road and traffic network in which the system is implemented. Travel time reduction can be in the order of 8 to 25% (Proper & Cheslow 1997). Booz Allen Hamilton (2004) reported that an ATC system such as SCATS could result in a 7 to 30% travel time reduction and a reduction in the number of stops by approximately 40%. Austroads (2003) identified similar results for the implementation of ATC systems with the addition that delays have been shown to be reduced by between 15 and 44%.

As traffic control efficiency reaches its practical limit, further benefits in urban travel management will come mostly from the development of demand management policies inducing modal and time shifts.

6.11 Active Transit Signal Priority

6.11.1 Background

Active transit signal priority (TSP) involves the real-time sensing of public transport vehicles and the adjustment of signals to better progress their movement. Sensing of vehicles can be either point based or continuous. Road loops and vehicle tags, a point based approach, are the most common to vehicle sensing. Here vehicle tags interact with road loops to make calls for priority. There is a growing trend towards the use of GPS based systems for more continuous monitoring of vehicles.

The most common signal responses in relation to priority are:

- Green extensions – where a bus or tram is sensed and expected to arrive just after a green phase is due to finish. The signal therefore extends the green time to enable the public transport vehicle to pass through the lights.
- Recalls/red truncation or early greens – where the bus/tram is expected to arrive before the green phase. Here the red phase is closed down early and the signal light phases are re-organised such that a green phase can be brought forward to assist the public transport vehicle.
- Special phases to assist public transport vehicles such as special movements like turning which only public transport vehicles take or special phases to clear queues in front of buses/trams.

There are two main approaches to TSP:

- Conditional priority – where public transport vehicles are allocated TSP within a series of limitations or constraints. These constraints act to balance the needs of public transport vehicles for priority against the needs of other road users. Examples might include:
  - public transport vehicle occupancy – to ensure priority is only provided for highly used buses or trams
  - traffic queue length – such that priority is not provided if traffic queues are too long
  - traffic volume/capacity ratio (or degree of saturation) – to balance the need for priority against the need of other road users to clear the intersection
  - time since priority last called – where priority may not be provided if time has not been provided for the intersection to clear traffic queues resulting from priority calls.
- Unconditional priority (or pre-emption) – where priority at the signal is provided immediately to ensure the public transport vehicle can pass through the intersection. Signal priority given to trains at level crossings is the most common example of unconditional priority.

Two further groups of active TSP strategies are:

- Direct priority – where traffic signals provide an immediate priority at the next intersection where the public transport vehicle is approaching.
- Indirect priority – where traffic signals some way ahead of the public transport vehicle are adjusted to clear traffic downstream such that the bus or tram can proceed more easily through following intersections.

Indirect priority is suggested as a more appropriate approach where there is significant traffic congestion.

Further, more detailed discussion of active signal priority for public transport can be found in Austroads (2007b and 2007d) and Currie (2006).

6.11.2 Best Practices in Active TSP Provision

TSP requires a balance between benefits to transit and impacts on other road users. The aim is to maximise transit performance while minimising the impacts on others. Table 6.11 outlines best practice in this optimisation.

Table 6.11: Optimising TSP performance – best practice

Good practice	Why
Avoid excessive priority	Benefits of TSP systems to provide effective transit decline at high degrees of intersection saturation. At road saturations above 1.0 there is often no benefit at all. This is because buses (and trams) share road space (and time) with traffic. If the traffic system is seriously disrupted, as a result of excessive green time in providing TSP, the traffic queues that result can act to disrupt public transport as well as general traffic.
Implement conditional priority: • add constraints to maximum and minimum green times • use weighting systems which encourage some phase retention to reduce delays to non-transit vehicles • initiate priority only when buses are late.	Constraining the time available for extension or early provision of green phases is a common approach to balance time inputs for all road users. Some examples are: • The degree of saturation at each intersection is used to compute a 'spare green time' value. This is the difference between the actual degree of saturation occurring and the target saturation which traffic engineers have agreed for each intersection. • Many TSP systems also tend to permit 'priority free' running of the traffic signal system after priority has finished enabling traffic flows to be re-balanced. This includes limits to the number of consecutive signal cycles where priority can be called. • TSP should be targeted to only buses (or trams) which are running late.

Good practice	Why
Consider need for indirect priority/traffic metering	Indirect priority approaches, where traffic signals far ahead of the public transport vehicle are adjusted to clear downstream traffic well ahead of arrival at intersections are also considered good practice in TSP. This approach is related to 'green wave' measures adopted for area traffic control systems but applied to TSP. A variation of this approach is to 'meter' the number of vehicles within the road network thus limiting congestion and associated queues. This approach is considered particularly effective for systems prone to high congestion levels (and hence ineffective TSP).
Consider need for active pedestrian detection	Safety for pedestrians (and other road users in general) is considered one of the most important principles in designing traffic signals. Warrants for the design of signals identify minimum pedestrian clearance times to ensure slower pedestrians can clear crossings safely. This acts as a timing constraint which limits how signals can be 'closed down' to permit TSP. Pedestrian detection devices ensure don't walk phases can be run only when demanded, freeing up time in the signal system to provide green time for all intersection users.
Phase compensation	Phase compensation occurs when green time removed for transit vehicles is replaced in following cycles. It is a strategy which permits traffic queues built up as a result of priority to be dissipated soon after priority events. As a result it acts to balance demands for time between road users. However in dissipating queues it can act to assist the progress of transit vehicles.

Source: Austroads (2007f), summarised.

Accuracy in estimating the arrival time of buses at signals is a major requirement for successful TSP design. If buses arrive before predicted arrival times, signal priority (such as a green extension) may be called and not used wasting time for other road users. If buses arrive after predicted times, they may not receive priority even though extra green time has been provided. Several factors can act to improve the accuracy of bus arrival time estimates, as outlined in Table 6.12.

Table 6.12: Ensuring accurate arrival time estimates

Good practice	Why
Continuous vehicle detection and automatic vehicle location systems	Short range detection of buses causes 'abrupt' needs for priority which can often not be catered for within the safety requirements of signals. A better approach is to gradually adjust cycles by a smaller amount using longer range advance detection (an indirect priority approach). Where detection is close to signals abrupt 'aggressive' signal changes are required which can seriously disrupt traffic. A range of criticisms of loop detection systems have been made: • Loop-based systems can be vulnerable to failures in detectors. Clearly vehicle tracking is not possible in a loop-based system without working detectors and hence it is less accurate. • Loop-based systems are also imperfect tracking systems in that they only detect vehicles at certain points. If vehicles are delayed between the detector point and the stop line then the provision of signal priority may be wasted. The use of automatic vehicle location (AVL) systems to provide more continuous monitoring of vehicle locations can assist in estimating the arrival time of vehicles more accurately. This strategy can also be combined with techniques such as 'green wave' or 'rolling horizon' to provide better estimates of arrival times at upstream stops and adjustments to these stops over a longer period (an indirect strategy).

Good practice	Why
Removing approach stops	An important factor affecting the accuracy of vehicle arrival prediction is the location of nearside or approach stops at intersections. When stops are located near to signals there is much variation in the amount of time it will take for the bus to reach the stop line. Travel time will be much slower if passengers board at the stop than if the bus proceeds without stopping. This means the TSP system must estimate an average time considering both alternative outcomes. An alternative approach is to ensure that priority is not called when priority vehicles have to board/alight passengers at approach stops (e.g. link the activation of the priority to bus doors). Relocation of approach-side stop to far-side locations is considered more compatible with effective priority provision. Approach stops cause more delays in TSP applications than equivalent departure stops. Removal of approach stops and their replacement to far-side locations was shown to reduce delays to buses by almost 50%.
Phase compensation	Phase compensation occurs when green time removed for transit vehicles is replaced in following cycles. It is a strategy which permits traffic queues built up as a result of priority to be dissipated soon after priority events. As a result it acts to balance demands for time between road users. However in dissipating queues it can act to assist the progress of transit vehicles.

Source: Austroads (2007f), summarised.

6.11.3 System Monitoring/Reporting

The measurement and recording of priority calls and the take-up and success rate with which calls are used effectively by public transport vehicles are important factors in understanding if priority is performing well. Importantly, the system should monitor the performance of the signals not just the transit vehicles. Understanding how and why priority calls were made is as important as understanding how the outcome of successful calls affect transit vehicles.

A major potential barrier to monitoring and understanding traffic signals based on area traffic control systems is that they are principally designed for traffic management not public transport vehicle management. Good system monitoring requires:

- continuous reporting of priority calls/public transport vehicle progression
- monitoring of traffic signal decision processes in relation to priority
- staff resources for monitoring and optimisation.

6.11.4 Recording of Public Transport Benefits

In order to justify TSP it is necessary to measure how it benefits public transport services. Benefits can include:

- reduced travel times
- improved reliability
- reduced vehicle and crew resource requirements resulting from the above
- increased patronage resulting from the above.

The benefits of the first two items are passenger related, hence identifying how many people benefit and by how much is an important input to benefit assessment. However these improvements are rarely measured in priority systems. Overall, best practice TSP would undertake continuous monitoring of:

- transit travel time and reliability impacts
- monitor impacts on transit crew and fleet utilisation
- monitor for increased public transport patronage.

6.12 Complex Signalised Intersection Situations

Special treatments may be required to consider more complex intersection layouts. A number of these treatments are outlined in this section. However, many of these situations will require advice from jurisdictional specialist signal operations engineers who can provide advice on appropriate phasing sequence options, associated model inputs or other critical elements.

This section presents operational aspects of special signalised intersection treatments. For further guidance on traffic signal display and location aspects of their use, refer to the Guide to Traffic Management Part 10 (Austroads 2019d) and AS 1742 Parts 2 and 14.

6.12.1 Seagull T-intersections

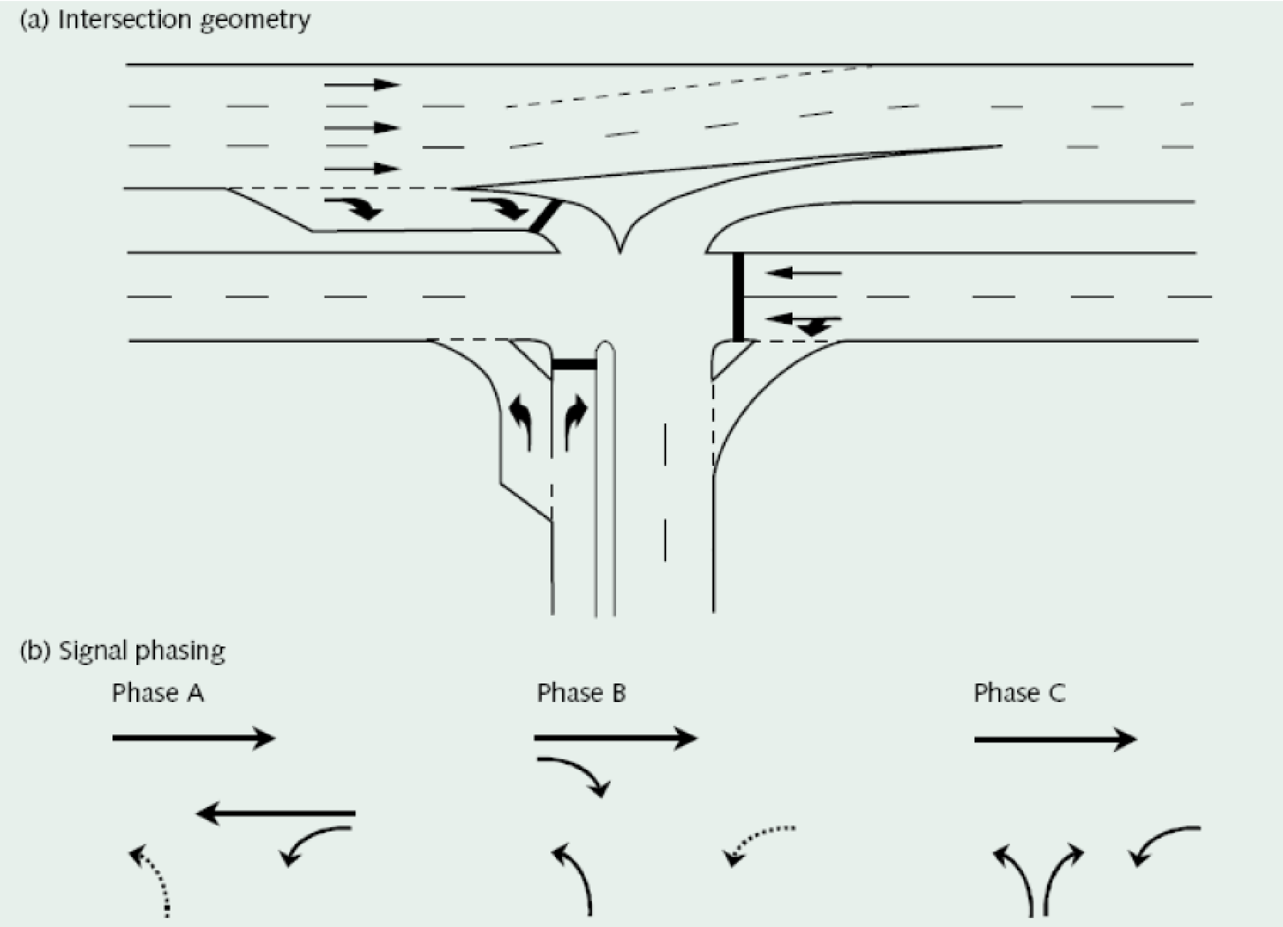
The purpose of a 'seagull' treatment of a signalised T-intersection is to avoid stopping through vehicles on the major road, approaching from the left of the T-intersection stem as shown in Figure 6.21(a). This through movement is not signal controlled and operates continuously as shown in Figure 6.21(b). However, this movement could be signalised in order to make provision for pedestrians crossing. When there is pedestrian demand, the through movement would be stopped when the side road movement operates, e.g. in Phase C in Figure 6.21(b).

Generally, traffic signals should be installed on seagull intersections only where right turn vehicles from the stem of the T-intersection do not have to merge with through traffic on the departure and weave across through traffic to turn left just beyond the signals. Any merging by these right turn vehicles can result in rear-end collisions.

If traffic has to merge on the departure, the safest option is for through traffic in the left-most lane to merge to its right. This means providing right turn vehicles from the stem of the T-intersection with their own lane or lanes on the departure as shown in Figure 6.21(a).

A capacity and performance evaluation should be carried out to determine if the seagull operation is more efficient than other intersection design options. This should account for lane under-utilisation on the major approach road from the left of the T-intersection that is likely to be caused by this treatment. For key traffic management selection considerations at seagull T-intersections, refer to Part 6 of the Guide to Traffic Management (Austroads 2019c).

Figure 6.21: Seagull T-intersection geometry and signal phasing

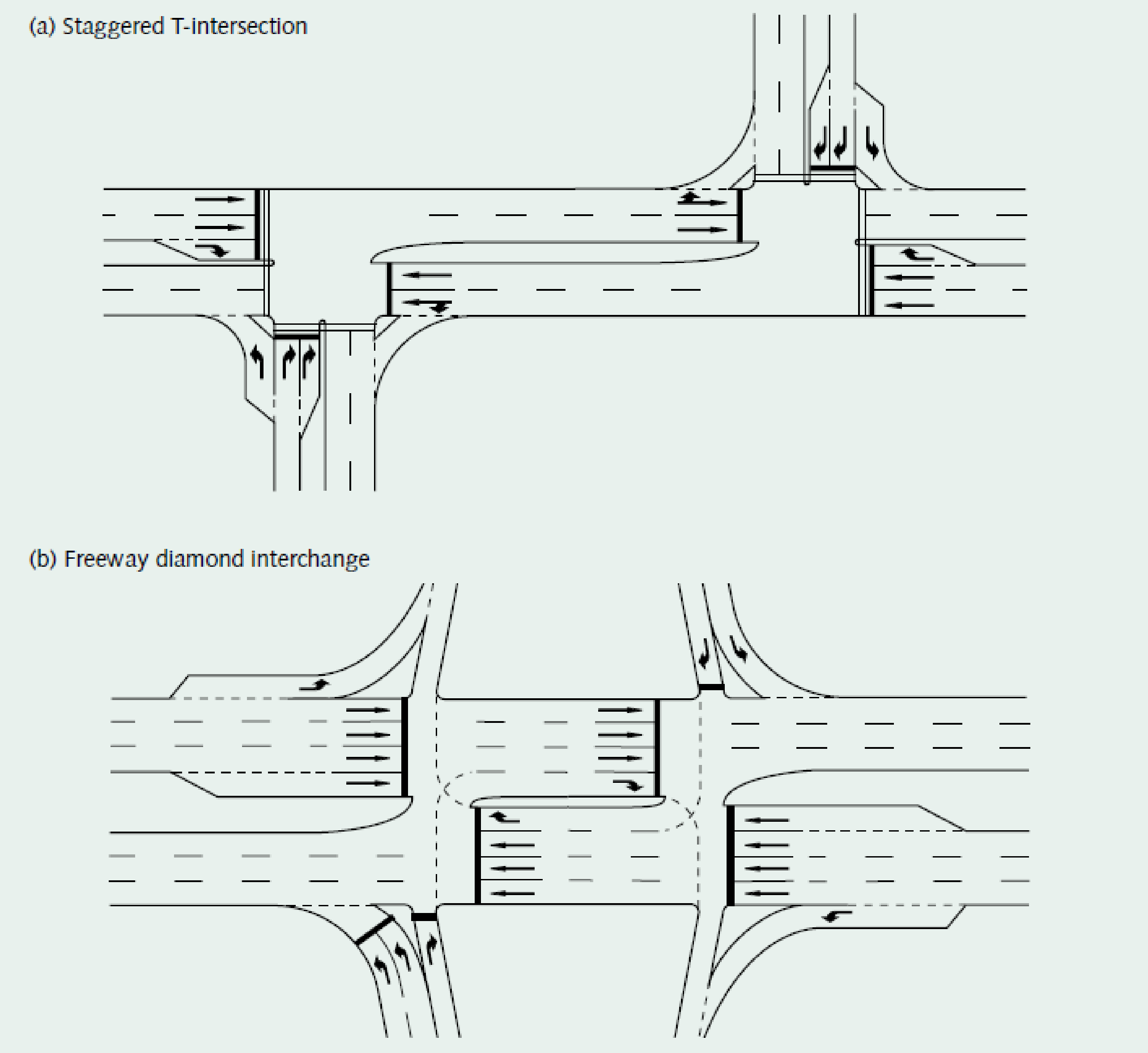


6.12.2 Paired Intersections

'Paired intersection' is a term used for two closely spaced intersections with limited queuing space between the intersections (i.e. internal approaches). Typical examples are staggered T-intersections and freeway diamond interchanges, as shown in Figure 6.22(a) and (b). Intersections with a wide median have similar characteristics.

Paired intersections are regulated by either a single traffic signal controller using built-in offset arrangements achieved through special phasing arrangements, or by two separate signal controllers that are linked under a coordination signal system.

Figure 6.22: Example of staggered T-intersection and freeway diamond interchange



Paired intersections may use an early cut-off green period, to allow an upstream signal to be terminated earlier than a downstream signal in order to minimise queuing on internal approaches. For additional guidance on this type of operation, refer to Appendix G.4.5.

Severe unequal lane utilisation may be observed due to heavy origin-destination flows in paired intersection systems, e.g. 'dog-leg' movements at staggered T-intersections. This should be taken into account in designing geometry and signal phasing for paired intersections.

Management of queuing in internal approaches of a paired intersection system is important to avoid blockage of upstream signals by through and turning vehicles queued in internal approach lanes. Early cut-off and early start phasing arrangements, simultaneous offsets and shorter signal cycle times are useful methods for this purpose.

It is important to ensure that adequate queue storage spaces are provided for vehicles turning right from internal approaches to freeway entry ramps.

With paired intersections, care should be taken to avoid the potential 'see through' problem, i.e. downstream green signals being seen by motorists stopped at the upstream stop line (refer to Part 10 of the Guide to Traffic Management, Austroads 2019d).

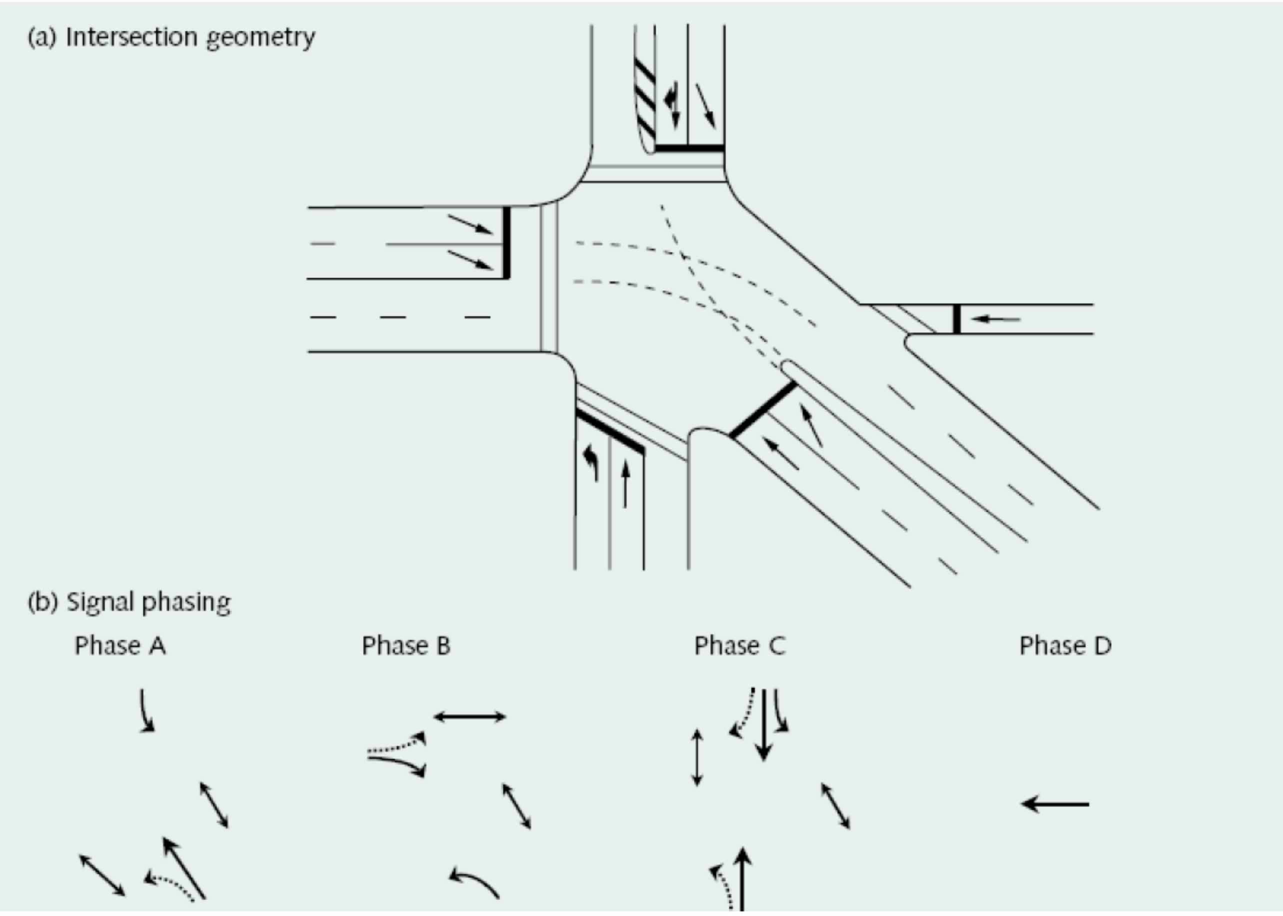
For key traffic management selection considerations for staggered T-intersections and freeway interchange ramps, refer to Part 6 of the Guide to Traffic Management (Austroads 2019c).

6.12.3 Intersections with More than Four Legs

At intersections with more than four legs, there are potentially more than four origin-destination movements from each approach road. The design of lane arrangements and signal phasings for such intersections is a significantly more complex task. Where allowed, U-turn movements will also need to be considered in the design, refer to AS 1742.14. Generally, these complex intersections would be treated on a site-specific basis.

An example of a five-legged intersection geometry and phasing arrangement is shown in Figure 6.23.

Figure 6.23: Example of intersection with more than four legs



The complexity of signal design for such intersections depends on the number of conflicting vehicle movements. The main aim is to minimise the number of phases as much as possible by eliminating some of the conflicting movements. This may mean banning some movements by using regulatory signs, introducing one-way approach and one-way exit conditions, or introducing partial or total road closure. Where movements are banned, alternative routes should be available and may need to be signposted as such. In Figure 6.23, the east leg is a one-way approach, and the right turn movement from the west leg to the south leg is banned.

Signalised crossings may require special attention, depending on the vehicle movements permitted in the same phase, to ensure that there are no safety problems. The inclusion of signal-controlled bus, bicycle, or tram lanes can further complicate the signal phasing for this type of intersection. Where possible these special vehicles should be controlled by normal vehicular displays.

For intersections where legs intersect at other than 90° angles, care needs to be taken to avoid the potential see-through problem, by ensuring that the green signals on one leg are not seen by drivers on an adjacent leg. For further guidance, refer to Part 10 of the Guide to Traffic Management (Austroads 2019d).

6.12.4 Signalised Roundabouts

Roundabouts are generally safer than signalised intersections and their capacity can be comparable to signalised intersections. However, if an existing roundabout is performing poorly in terms of delay on several approaches, signalisation should be investigated. Moreover, signalisation of roundabouts can provide safety benefits for pedestrians and cyclists. Options that may be considered include:

- metering in advance of a roundabout entry
- full or partial signalisation at the junction of roundabout entries and the circulating carriageway.

These options are discussed in Part 6 of the Guide to Traffic Management (Austroads 2019c). For guidance on signal displays used at signalised roundabouts, refer to Part 10 of the Guide to Traffic Management (Austroads 2019d). Guidance on road design considerations at signalised roundabouts is provided in Part 4B of the Guide to Road Design (Austroads 2015c).

Metering of roundabouts may be required when traffic arrivals on one approach are high and constant (or uninterrupted), resulting in limited opportunities for the vehicles on the yielding approach to enter the roundabout causing excessive queueing and delays on that approach. A review (Green 2015) indicated that metering of roundabouts should be considered when demand is close to capacity and there is uneven demand (i.e. when the metered approach demand accounts for 35% or less of the demand from metered plus controlling approaches).

6.12.5 Railway Level Crossings

If a road traffic signal installation is located in close proximity to a railway level crossing, there is a probability that:

- vehicle queues from a road traffic signal may extend across adjacent rail tracks
- vehicle queues from a railway level crossing may extend into nearby signalised intersections.

During such occurrences, special provision may be required to implement a phase to clear or limit queuing issues. This may be accomplished through interlinking a road traffic signal with railway level crossing controls.

Queue detection (Section 6.8.8) may be used to identify the presence of vehicle queues near a crossing. This may be required to ensure that:

- queues generated by a traffic signal do not extend across railway tracks
- queues resulting from level crossing operation will not interfere with traffic movements at the road intersection.

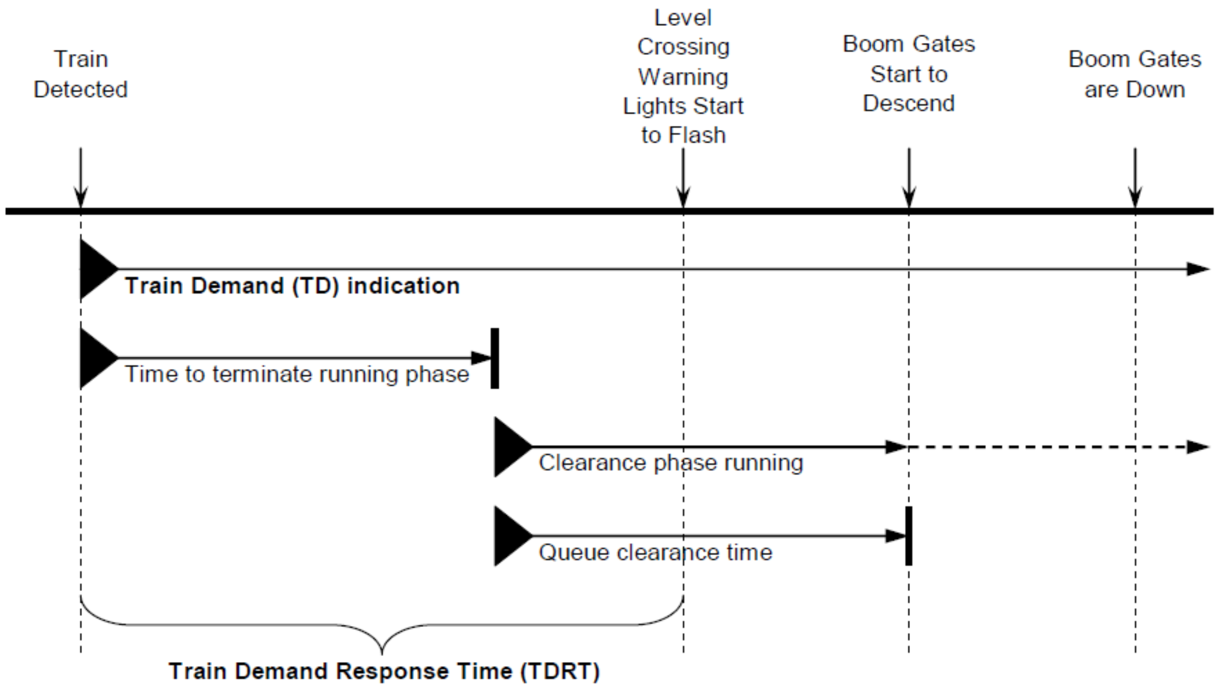
In order to detect an approaching train, an interface must be established between a road intersection traffic signal and adjacent railway level crossing control. A train must be detected at a time in advance of its arrival at a level crossing. This advance time period is determined to ensure that a traffic signal is able to respond to a train demand and be in a state which is satisfactory for level crossing operation when a train approaches a level crossing.

The advance time period required to detect a train is dependent on the worst possible phasing sequence at a site. This should consider:

- the worst scenario for terminating a running phase, which occurs when a train is detected immediately after a running phase has initiated and cannot be terminated until its safe minimum time has been satisfied (typically the worst case would be due to pedestrian movements)
- time required to clear queued vehicles, which is dependent on the queue length between the intersection stop line and a level crossing (during different times, days and considering any unusual patterns) and needs to consider the vehicle types comprising a queue (e.g. a B-double would take considerably longer to clear than a car)
- boom gate delay (time between level crossing warning lights beginning to flash and when boom gates commence descending)
- time required for a vehicle to clear an intersection conflict zone and pass the level crossing before the warning lights start to flash (generally, the worst case time will be for a right turn filter vehicle, but the time may also depend on vehicle type).

The diagram shown in Figure 6.24 depicts these time periods. The advance time period required to detect a train is referred to as the train demand response time in the figure.

Figure 6.24: Advance time period required to detect a train



Source: Roads and Traffic Authority NSW (2010a).

Establishing the advance time period required to detect a train will aid in determining how far in advance of a level crossing train detection devices need to be positioned. Detection and other signal requirements should be determined in consultation with the appropriate railway authority.

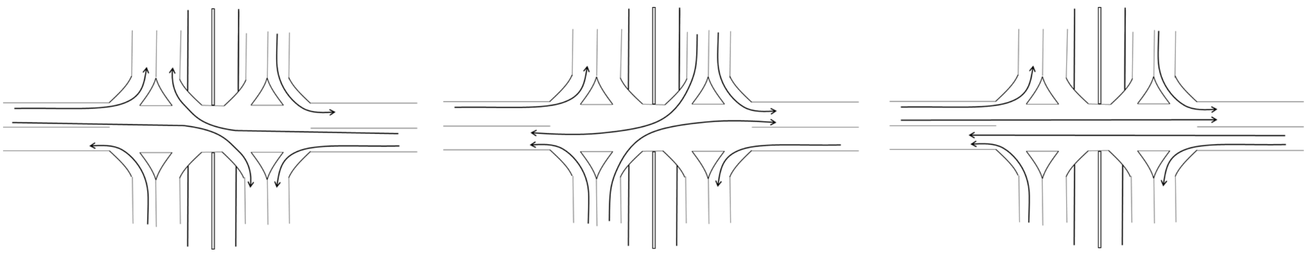
Appendix I.1 presents an example of traffic signal phasing, timing and detection at a signalised intersection interfaced with a level crossing.

For further guidance on traffic detection and interlinking control at railway level crossings, refer to Institute of Transportation Engineers (2006), Roads and Traffic Authority NSW (2008b, 2010a, 2010b) and VicRoads (2014). General guidance on traffic management at railway level crossings is provided in Part 6 of the Guide to Traffic Management (Austroads 2019c). For information on signal displays, signs and markings at or near railway level crossings, refer to Part 10 of the Guide to Traffic Management (Austroads 2019d).

6.12.6 Single Point Urban Interchange

A single point urban interchange aims to manage large volumes of traffic with limited road space. Traffic movements are controlled at a central single point, hence the name. The operation of a single point urban interchange is shown in Figure 6.25.

Figure 6.25: Single point urban interchange

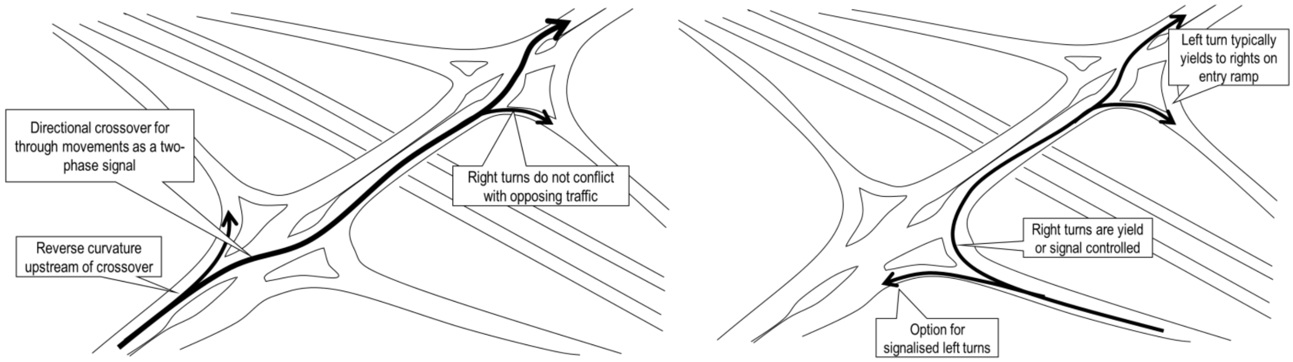


Source: Adapted from Missouri Department of Transportation (2013).

6.12.7 Diverging Diamond Interchange

A diverging diamond interchange configuration eliminates the need of right-turning vehicles to cross through movements by switching the direction of traffic at the interchange. The diverging diamond interchange can improve the operations of turning movements to and from the motorway and reduce conflict points compared to conventional designs. The key features of the diverging diamond interchange are shown in Figure 6.26.

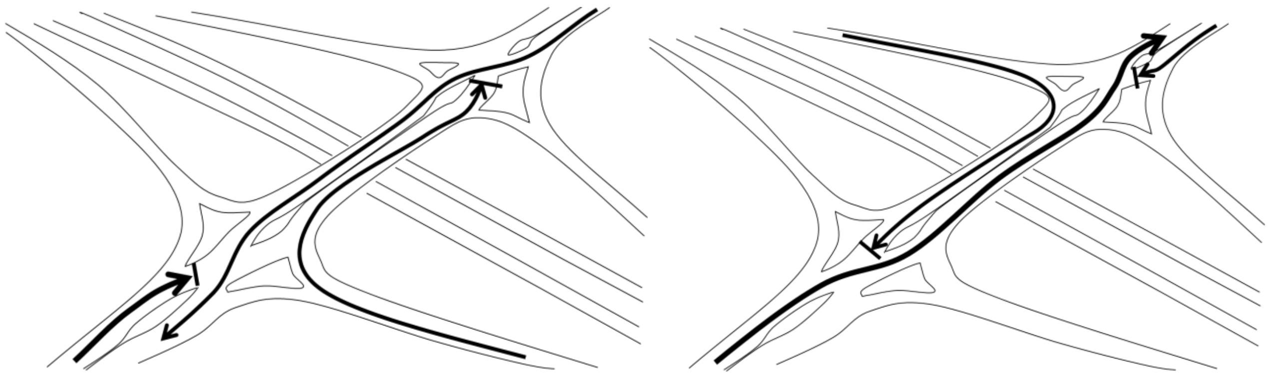
Figure 6.26: Key features of a diverging diamond interchange



Source: Adapted from Federal Highway Administration (FHWA) (2014).

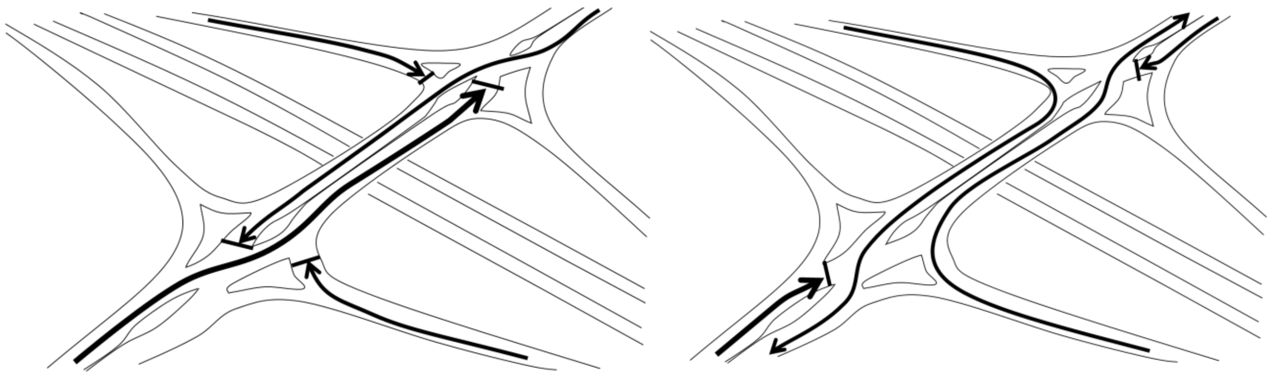
There are two options for operating the diverging diamond interchange. The first is to favour the cross-street traffic (Figure 6.27) and the second is to favour the exit ramp traffic (Figure 6.28).

Figure 6.27: Operation of diverging diamond interchange favouring the cross-street traffic



Source: Adapted from FHWA (2014).

Figure 6.28: Operation of diverging diamond interchange favouring exit ramp traffic



Source: Adapted from FHWA (2014).

6.13 Implementation

This section discusses the commissioning of traffic signals and coordinated systems.

6.13.1 Commissioning Traffic Signals

Prior to commissioning, the traffic signal installation should be checked to ensure that it is in accordance with the design and that all equipment is correctly installed and operating. Appendix J provides a checklist.

After traffic signals are first switched on two initial tasks need to be undertaken in order to:

- check that detectors and signal groups have been wired correctly
- trim the coordination plans.

Some checking can be carried out while the traffic signals are operating in isolated mode and some with the system operating in SCATS Flexilink mode, before the system is switched to SCATS Masterlink. For example, obvious errors in connection of detectors and green groups will be apparent from initial checks of the data displayed by the SCATS System Monitor. Incorrect wiring may be indicated if any of the following conditions are present:

- same data on two detector lines
- unexpected lane utilisation
- zero volume and/or consistently high DS
- group green time not equal to the sum of the phase times used by group
- in SCATS, a high V_K/V_O ratio, i.e. ratio of reconstituted volume to measured volume.

In general, data should be checked for unusual or unexpected values.

While this method (i.e. checking system data) quickly checks for obvious errors that would adversely affect dynamic control, all detectors should be checked on-site at the local controller. The detector LEDs should be observed and checked to ensure that they operate when vehicles pass over the required detector.

To check that signal groups have been wired correctly, again the SCATS System Monitor can be used. The green time measured on-site should be checked against the corresponding green time shown in the System Monitor.

6.13.2 Commissioning Coordinated Systems

SCATS is the coordination system predominantly used in Australia and New Zealand, and while attempts have been made to make the following guidance as generic as practicable, where it is necessary to illustrate a point with specifics, SCATS is used as the basis[2].

Since coordination plans are usually designed on historical data, it is very rare that traffic conditions will be the same when the system is operational and, therefore, the system must be trimmed. Once detectors and signal groups have been checked, phase splits and offsets can be trimmed. At this point the most significant measures of system performance are:

- queue length, particularly at critical intersections
- (in SCATS) degree of saturation (DS).

Particular remedial actions in response to observed conditions in the trimming process at this stage will be specific to the coordination system being implemented. See the system user manual, e.g. Roads and Traffic Authority NSW (2000) for details. However, some general points of good practice can be noted.

2 Licensed SCATS users can obtain more detailed SCATS specific information on implementation in Roads and Traffic Authority NSW (2000) and related system documentation.

Implementation of traffic signals and coordinated systems good practice

The priority of tasks when initially implementing a system is to have phase splits, then cycle time and finally offsets operating satisfactorily. This should be achieved at all times during the day, including evenings and weekends, as well as during peak periods. Trimming and monitoring must be undertaken at these times.

It may become apparent that changes to the road environment are either necessary for system operation, (e.g. extending parking restrictions to ensure strategic detectors operate efficiently), or are desirable to improve system operation, (e.g. a change in lane marking to increase the utilisation of a lane used by turning vehicles). Therefore, during this period, each intersection should be systematically checked to determine if system operation would be improved by the following measures:

- Changes to intersection geometry or phasing, particularly to increase capacity associated with short turning bays which are overflowing or shared turning lanes which block through traffic; here increased length of a turning bay is desirable or repeat phasing arrangements should be examined.
- Introduction of turn restrictions to increase through capacity, mainly during peak periods. However, remember to check that reasonable alternatives exist for those wishing to make the prohibited turn.
- Extended parking restriction, both in time and/or length of road restricted, should be used to ensure strategic detectors operate efficiently and when increased capacity is required.
- Changes to lane markings to improve utilisation of existing lanes.
- Changes to lane markings to improve capacity and/or remove confusion. e.g. it may be appropriate to extend lane markings onto the intersection to guide traffic making turns across a wide intersection.

The cause of all queues should be checked. Examination of these queues can identify faults in data used by the system. In particular, check if:

- the queue is due to traffic turning from side streets, in which case an offset change may improve the situation
- the queue is due to truncation of a platoon, in which case phase splits and offsets should be checked
- the queue is the result of insufficient green time; again phase splits should be rechecked.

The system should be observed for ‘shock waves’, usually caused by poor offsets. These shock waves (a sharp deceleration of vehicles in a moving platoon) are best observed from a helicopter or by standing at the roadside. They are not always apparent when driving through the system. Shock waves cause significant reduction in capacity and therefore should be eliminated.

Where they cannot be eliminated by a change in offset, e.g. where there is a heavy movement turning into an arterial road followed by heavy through movement along that road, consideration should be given to holding the main through platoon further back in the system to avoid direct conflict with the turning movement. Care should be exercised in this approach since the capacity loss caused by holding the main platoon back may be greater than that due to the shock wave.

The offsets for bus operation should be observed. Buses can cause significant loss of capacity at intersections and therefore require special consideration. Offsets should be checked to determine if a different offset would clear buses through the system quickly. Particular attention should be paid to bus stops between closely spaced intersections. This has an obvious advantage for bus users but also can be of advantage to other road users if the additional capacity resulting from clearing the bus is greater than the loss of capacity caused by the poor offset.

Generally, system operation should be checked during the week following the change, at times of day when the problem was identified, to ensure an over-correction did not occur. Changes in data should always be checked in the following week.

6.14 System Monitoring and Maintenance

As noted in Section 3.6.3, although adaptive traffic control systems provide substantial benefits compared to fixed-time systems, the performance of adaptive systems may deteriorate if not kept properly tuned. It is therefore important that signal installations are checked periodically to ensure that the signal operation accommodates any changes in traffic or the environment that may have occurred (e.g. increased or decreased demand volumes).

In general, feedback from road users may be sufficient to ensure that the phasing and signal timings at isolated intersections not forming part of a coordinated system are appropriate. In coordinated systems the symptoms of non-optimal operation may be more subtle, and a more formal program of operational review is recommended. In both cases feedback from electrical maintenance staff and other traffic professionals should be encouraged to quickly identify problems and help ensure that signals continue to operate as efficiently as possible.

6.14.1 Monitoring Individual Sites

Following implementation and fine-tuning of signals, monitoring and evaluation of the operation will verify (or otherwise) the adequacy of assumptions made in the design. Inadequate kerbside parking controls or unforeseen variations in traffic (demand) flow, are examples of problems that may be identified.

When a signalised intersection is commissioned, users may experiment with alternative routes during the fine-tuning period. Thus, the timing of the monitoring and evaluation process requires careful consideration. The process may need to be repeated a number of times.

While the design may be based on selected peak traffic flows, monitoring and evaluation should also consider conditions during off-peak periods, public or school holidays, and unusual traffic flow periods.

The monitoring and evaluation process essentially repeats the design process using the data collected after the commissioning to verify the adequacy of the design in terms of safety and efficiency. If deficiencies are evident it may be possible to implement changes to improve performance, e.g. fine-tuning of signal timings, phase sequencing, restrictions on movements, and extension of kerbside controls.

In some cases, deficiencies can only be corrected by a complete redesign of the channelisation associated with the signal installation, particularly when the design has been constrained. The decision to implement a redesign involves a complex process of engineering assessment.

Appendix K provides a comprehensive checklist for monitoring and evaluating the operation of an individual site.

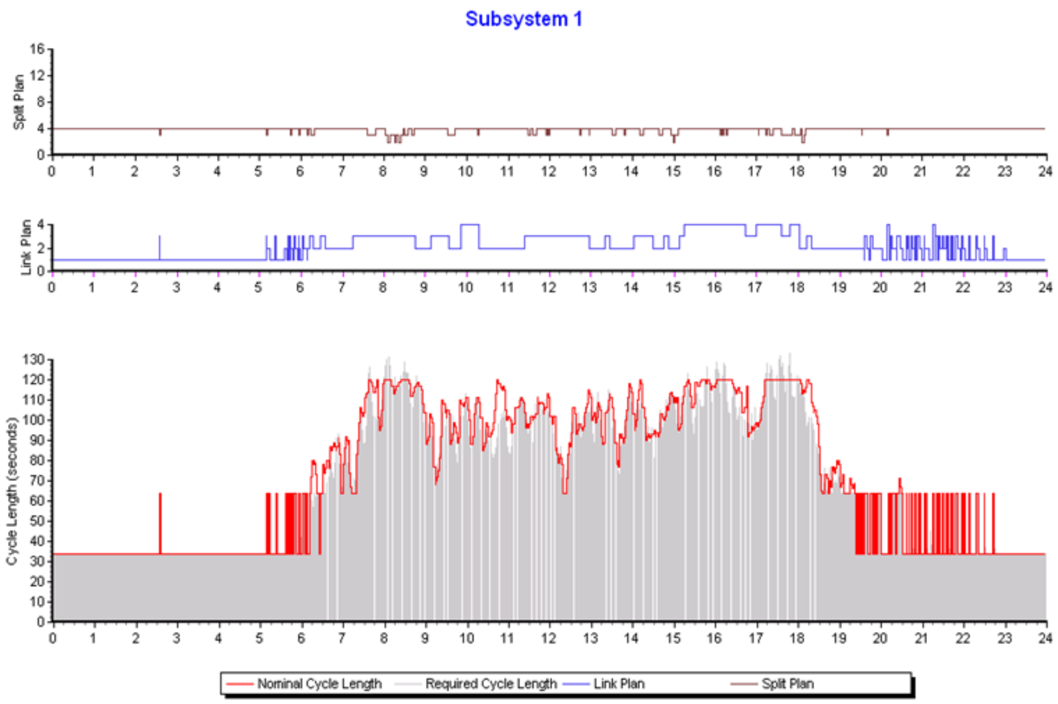
6.14.2 Monitoring Coordinated Systems

For coordinated systems, at the end of the first month after the installation of the system, the following should be monitored to ensure correct operation:

- all plans are being selected and are appropriate for conditions when selected
- offsets and phase splits are appropriate for all levels of demand
- where applicable, linking between groups of signals is correct
- cycle time responds to changes in traffic demand but the cycle time profile is stable throughout the day.

In SCATS the TrafficReporter program is invaluable in checking system performance and should be used at least every two or three months. The cycle time profile and the selection of split and link plans can be quickly checked from the graphical plot produced by the program (Figure 6.29).

Figure 6.29: Cycle time profile and link and split plan selection from SCATS TrafficReporter



All the strategic data that SCATS uses for its control algorithms come from the detector loops in the road. It is therefore imperative that the detector system is well maintained.

In general, monitoring and maintaining the system is oriented towards ensuring that the traffic engineer is aware of on-road traffic conditions and of SCATS response to those conditions. As those conditions change, e.g. the opening of a shopping centre or changes in the road system, the monitoring procedure will identify those changes that are outside the range of SCATS ability to adapt. Further action by the traffic engineer would then be required.

The process of ensuring that a signal coordination system is operating satisfactorily is known as **optimisation**. It can be undertaken via audits of performance at several levels depending on whether a routine check of operations, a major review arising from significant changes to the road network or something in between is required.

Table 6.13 outlines an example of an optimisation/audit model. It draws on the SCATS system for illustrative purposes, although the principles could be applied to any system.

Table 6.13: Coordination system optimisation/audit model

Audit level	Purpose	Description
1. Basic intersection control data validation	To validate basic intersection control data by checking the SCATS site data to see if it matches the traffic signal controller's local time settings.	This is the most fundamental requirement for efficient and effective operation. If this data is not correct, then the performance of an intersection is fundamentally compromised. SCATS operates on several different levels, the site data is the basic building block. From it SCATS determines when phases terminate, when pedestrian movements terminate and the coordination point for intersections and sub-systems. Therefore, it is extremely important that this data be correct, if it is wrong it can affect not only this controller but the entire coordination system.
2. Intersection audit	To audit the physical installation and functional operation of a traffic intersection site to determine if they are complete, functional, reliable, and appropriate.	Physical inspection of traffic signals at the site as per worksheet: • functional inspection of traffic signal, hardware and software control • completing the designed check sheet • analysing the check sheet • taking corrective action • following up the corrective actions.
3. Strategic data audit	To improve conditions for light off-peak traffic, and provide the basis for correct selection of traffic control parameters within the network under consideration.	Applies to one or two SCATS sub-systems, which is the current minimum segment of strategic control in Masterlink operation of SCATS. The scope of this audit extends to the following SCATS control items in a subsystem: • tactical control • green time occupancy collection • green time phase split control • cycle length control • offset control • absolute minimum cycle length for vehicles • minimum cycle length for all vehicle phases • minimum cycle length for all vehicle and pedestrian phases.
4. Minor network control	To improve conditions for off-peak, heavy off-peak, and peak traffic, and provide the basis for correct selection of traffic control parameters within the network under consideration.	This procedure is an audit and assessment of the operation of traffic signals when operating over a wide range of traffic conditions under Masterlink operation of SCATS. The intention is to specify the requirements for the operation of a traffic signal coordination system over a wide range of traffic conditions to provide optimum conditions for all traffic, on a proportionate basis. The scope of this procedure extends to the following SCATS control items in a subsystem: • offset data within and between sub-systems • green time phase split operation • cycle length operation • offset operation • maximum cycle length of each subsystem • optimum cycle length of each subsystem • cycle length response of subsystem • cycle length limit of network • optimum cycle length of network.
5. Major network control	As for level 4 but larger road network scope.	Requires level 4 procedures to be applied more extensively. Should include a quantitative analysis of traffic conditions and the performance of SCATS control under consideration. Such a quantitative analysis should provide detailed information on traffic conditions and performance of SCATS control. The analysis should identify the occurrence, extent, and severity of traffic congestion. The intention is to specify the requirements for the operation of a traffic signal coordination system over a wide range of traffic conditions to provide optimum conditions for all traffic, on a proportionate basis. Applies to major traffic routes with significant through traffic.

Source: Adapted from Roads and Traffic Authority NSW (2008a).

6.15 Signal Equipment Maintenance

Maintenance of traffic signal equipment is essential for effective operation. Integral components of an effective maintenance system are:

- speedy and accurate fault reporting
- fast response time to reported faults
- preventative maintenance
- lamp changing.

6.16 Emergency Vehicle Priority

The need for speedy response by emergency vehicles (EV) has long been recognised. The use of sirens and flashing lights to warn other road users, the obligation on other road users to make way for EV and the exemptions granted to EV from some or all of the road rules[3] are longstanding priority measures.

Other, non-regulatory measures to aid emergency vehicles are largely focussed on pre-emption of traffic signal operation, with route guidance measures in limited application. Traffic signal techniques that support emergency vehicle priority are listed in Table 6.14. To understand the potential impacts to the various road user groups of these techniques refer to Austroads (2015e). For further guidance on emergency vehicle priority refer to Austroads (2007f). For guidance on traffic signal displays used for emergency vehicles, refer to Part 10 of the Guide to Traffic Management (Austroads 2019d).

Table 6.14: Signal timing and phasing treatments to support emergency vehicle priority

Traffic signal treatment	Description
Active pre-emption of traffic signals when a vehicle is detected prior to arrival at an intersection	When an emergency vehicle is detected to arrive at an intersection (e.g. through in-vehicle transmitter/transponder), a green phase is provided as soon as it is safe to terminate the current phase. Generally, detection triggers pre-emption in the direction of approach of the emergency vehicle.
Special emergency vehicle phase for intersections near emergency vehicle facilities/stations	Activation of a specific phase for emergency vehicles at intersections adjacent to emergency vehicle facilities/stations when called. The phase may be activated by detectors/exit push buttons or via a phone call from the emergency services to the traffic management centre. Generally used where the exit from the facility/station leads directly onto the intersection (or in close proximity).
Special phase to clear queues at intersections near emergency vehicle facilities/stations	Activation of a special phase to clear queues at intersections near emergency vehicle facilities/stations prior to arrival of the emergency vehicle. The phase may be activated by detectors/exit push buttons or via a phone call from the emergency services to the traffic management centre. Generally used where the exit from the facility/station joins a road a short distance from the intersection (i.e. there is time for the queue to clear prior to the emergency vehicle reaching the intersection).
GPS tracking with an in-vehicle GPS unit and another at an intersection	The system predicts the arrival time of an emergency vehicle at an intersection and ensures an emergency vehicle receives a green period upon arrival. The system may also alter signal timings in advance in order to allow vehicles at the signalised intersection to move out of the way more easily and further decrease the emergency vehicle's travel time. If the route is unknown, the system can predict possible routes and implement a pre-emption strategy on each route eliminating route choices. Signal timings are returned to normal once the emergency vehicle passes through an intersection/progresses along a route.
Pre-determined route pre-emption plans	Manually implemented to improve progression on designated routes along pre-determined signal linking plans (e.g. using remote procedural control or through phone call to signal operators). May be best suited to fire service vehicles than to ambulances/police since the former have slower acceleration from a stationary position and thus benefit more from good signal progression, and they generally depart from a fixed base as opposed to an on-road callout, which is common from both ambulance and police services. Also used for organ donor (and VIP) escorts from airport to hospitals. May require close phone or radio contact to the traffic management centre (TMC) to avoid unplanned congestion along the route.

3 Exemptions and the conditions under which they apply vary according to jurisdiction. See Australian Road Rules and New Zealand Land Transport (Road User) Rules for details.

6.16.1 Emergency Vehicle Pre-emption Schemes

Emergency vehicle pre-emption schemes (EVP) are of several types (Austroads 2007b):

- localised schemes at or in the neighbourhood of EV stations
- route pre-emption schemes
- active detection at signalised intersections
- GPS tracking.

Localised schemes

The phasing and/or timing of traffic signals located close to an EV station are pre-empted on demand, either from a push-button at the station or a controller input activated by an in-vehicle transmitter, to provide the EV controlled, priority access to the intersection. Further details of this form of EVP can be found in Part 10 of the Guide to Traffic Management (Austroads 2019d).

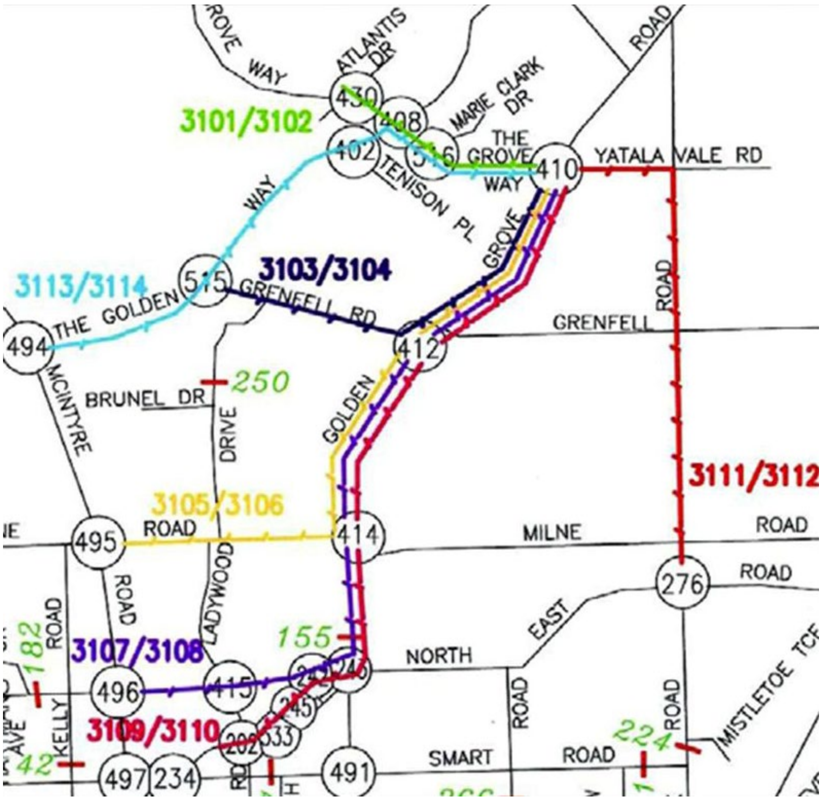
Route pre-emption

Route pre-emption utilises signal coordination systems to facilitate progress of an EV along a pre-defined route. It is based on the establishment of key routes from the EV fire station and individual route pre-emption plans. Figure 6.30 shows an Adelaide example (Baskerville 2006). The route pre-emption plan is designated by a four digit number such as 3103. This number identifies both the station (first two digits) and the route pre-emption plan (second two digits). Upon request for a call-out, a crew member phones the traffic management centre through a special phone connection and the centre activates the desired route pre-emption plan which the emergency vehicle will use to get to its destination. Once activated the route pre-emption plan alters the signal timings of each intersection along the route using SCATS to favour the progression of the emergency vehicle along its route.

Because the system is based on a pre-determined route pre-emption plan, it can be susceptible to unforeseen circumstances along its route such as traffic congestion. This problem can be overcome through the EV staying in contact with the traffic management centre so that the pre-emption plan can be restarted if not coinciding with the emergency vehicle’s progression. This could overcome the situation of an emergency vehicle falling completely out of synchronisation with the system and obtaining negative priority, i.e. stopping at many red lights (Austroads 2007b).

Route pre-emption schemes of this type are more suited to fire service vehicles than to ambulances because the former have slower acceleration from a stationary position and thus benefit more from good signal progression, and they generally depart from a fixed base as opposed to an on-road callout which is common for both ambulance and police services.

Figure 6.30: Emergency vehicle route pre-emption



Source: Baskerville (2006).

Active detection

There are three general methods used in EVP systems to detect the arrival of an emergency vehicle (Federal Highway Administration 2006a):

- Strobe activated – an infrared or light (optical) frequency transmitter is installed in the emergency vehicle and a roadside receiver is installed at an intersection to pick up the arrival of the transmitted signal.
- Siren activated – the noise frequency of a siren is employed to activate sensors at an intersection to identify the arrival of an emergency vehicle and activate signal pre-emption.
- Radio activated – a radio frequency signal is transmitted from a vehicle-mounted transmitter and received by a roadside receiver; a radio activated system is more susceptible to electronic noise when compared with the strobe activated system, but does not require line-of-sight reception.

Active detection is not common in Australia or New Zealand, but a Melbourne trial of a strobe based system has given encouraging results in terms of reduction in response times and improved safety (Bean & Studwick 2006).

GPS tracking

A GPS-based system utilises a GPS receiver which is installed both at an intersection and within the emergency vehicle. The system can ascertain the position of the emergency vehicle relative to a signalised intersection and can also determine the vehicle's speed. This enables the system to predict the estimated time of arrival of the emergency vehicle at the intersection (Austroads 2007b).

A GPS-based pre-emption concept using the STREAMS traffic management system is described in Transmax (n.d.). If the emergency vehicle's route is known, STREAMS ensures that the emergency vehicle receives a green phase upon arrival at an intersection and also alters the signal timings in advance. This allows vehicles at the signalised intersection to move out of the way more easily, hence decreasing the emergency vehicle's travel time. If the route is unknown, the system can predict possible routes and implement a pre-emption strategy on each route, eliminating route choices and returning signal timings to normal, based on the progression of the emergency vehicle. In both cases, signal timings return to normal once the emergency vehicle has passed through the intersection (Austroads 2007b, Transmax n.d.).

6.16.2 Evaluation

An evaluation of the various EVP technologies was reported in Austroads (2007f). Table 6.15 summarises the results.

Table 6.15: Evaluation of emergency vehicle pre-emption systems

EV priority measures and technologies	Objective	Quantitative impacts	Qualitative impacts
Route pre-emption plan	Reduce travel time to incident sites by improving progression on designated routes with pre-determined signal linking plans.	–	95% of respondents to a survey of operators in Adelaide expressed moderate to high satisfaction in improvement in travel speed and safety. 65% of operators found that loading the pre-emption plan was of moderate difficulty (Baskerville 2006).
Detection at signals	Clear traffic at an intersection before the arrival of an EV with a green phase by detecting its arrival before reaching the intersection.	Reduce response time by 14% to 23% and road crashes by 90% (Federal Highway Administration 2006a).	An infrared system was able to activate a signal at a distance up to 500 m in a Melbourne trial with no misses. Response time, stress and public safety were significantly reduced (Bean & Studwick 2006).
GPS tracking with an in-vehicle GPS unit and another at an intersection	Predict the arrival time of an EV and provide a green phase before and during its passage through the intersection.	Reduce response time by 20% in a trial in Illinois, USA (Proper et al. 2001).	–
Route guidance	Provide shortest path to incident site based on traffic information en route.	Reduce response time by 10% to 15% in New Mexico, USA (Proper et al. 2001).	Route guidance.

Source: Austroads (2007f).

6.16.3 Summary

A range of technologies has been successfully implemented in local and overseas cities to improve the response time of emergency vehicles. These technologies range from simple manually operated pre-emption of signal phases adjacent to a fire or police station to advanced GPS-based technologies. The response times of emergency vehicles have been shown to be reduced by 14 to 25%. Road crashes could also be reduced by up to 90%.

It is worth noting an important aspect of the low-cost, SCATS-based (manual) pre-emption scheme along a route to facilitate the progression of emergency vehicles to an incident site. It requires close phone or radio contact to a traffic management centre to avoid unplanned congestion along the route, but its use is always an improvement on the absence of any EVP system.

7. Systems and Procedures for Arterial Traffic Control – Others

7.1 Introduction

This section provides guidance in relation to systems and procedures for traffic control, except for traffic signal systems, which are covered separately in Section 6. It describes a number of systems that may aid network operations including lane management, variable speed limits and co-operative intelligent transport systems, and travel aid/road user information.

The systems described in this section are not only important to traffic control and network efficiency. They also support Safe System objectives by contributing to all four safety pillars. For example, lane use management systems contribute to safe roads, variable speed limits to safe speeds, travel aid and user information to safe users and co-operative intelligent transport systems to safe vehicles. While the design and operation of the systems themselves may be complex, the interface with road users and the information that they receive must take into consideration human factors and limitations. Failure to do this will compromise safety and the effectiveness of the systems.

7.2 Lane Management Systems

7.2.1 Lane Use Management Systems

Background

A lane use management system (LUMS) is used to control the movement of vehicles both in, and to and from, a lane. Functions can include lane opening/closure, capability to create a merge zone in advance of lane closures, and the special use of symbols such as bus, transit or truck lane symbols, and can incorporate dynamic control of speed zones. The system may be integrated with other road management systems such as ramp metering, variable message signs, variable speed limit signs and traveller information (e.g. diversions) to provide for overall corridor management. It also facilitates the implementation of incident management plans.

Lane use management is an essential part of reversible lane systems, shoulder lane use schemes and tunnel control systems as described in succeeding sections.

Lane use management is also increasingly being used on Australian and New Zealand freeways and motorways. Lane use management utilises lane control signals to control the movement of vehicles both in, and to and from, a lane. Functions can include lane opening/closure, capability to create a merge zone in advance of lane closures, the special use of symbols such as bus, transit or truck lane symbols. For further guidance on the application of lane use management on motorways refer to the Guide to Smart Motorways (Austroads 2016b).

Typically, LUMS directly includes the following components:

- lane control signs (LCS)
- LUMS control system.

The following items are not directly part of a LUMS but support its function:

- data stations
- variable message signs
- variable speed limit signs
- incident detection
- communications
- freeway gantries
- CCTV coverage.

LUMS lane displays

Lane control displays are described in Part 10 of the Guide to Traffic Management (Austroads 2019d). It covers the following:

- lane open and speed limit
- merge left, right or both
- lane closed
- exit lanes
- designated turning lane.

LUMS should be able to provide the following capabilities either proactively or in response to the following traffic management scenarios:

Table 7.1: LUMS capabilities for traffic management scenarios

Traffic management scenario	LUMS capabilities
Normal operations – low demand	Capability to create emergency stopping lane (not currently planned for use)
Normal operations – high demand	Manage merge areas by creating add-lane Maximise (prioritise) available road space Provide additional capacity by permitting shoulder-lane use
Incident management	Protect (make safe) incident area Provide quick access for emergency vehicles Maximise (prioritise) remaining available road space Manage merge areas by creating add-lane
Planned roadworks/events	Protect (make safe) works/event area Provide quick access for emergency vehicles Maximise (prioritise) remaining available road space Manage merge areas by creating add-lane
Contra-flow operations	Manage lane use on approach to contra-flow area

7.2.2 Reversible Lanes

A particular form of lane use management is the reversible lane. A reversible lane system (or tidal flow system) is one in which the direction of traffic flow in one or more lanes or shoulders is reversed to the opposing direction for some period of time. The road and traffic characteristics that provide beneficial circumstances for reversible lane operation are discussed in Part 5 of the Guide to Traffic Management (Austroads 2019b).

Lane reversal may be implemented by several systems:

- manual reversal
- moveable medians
- dynamic reversal.

These systems are usually put into operation on a daily basis during peak periods. Lane reversal may be made on a fixed-time basis (each day at predetermined hours) or on a dynamic basis in response to traffic demands. Fixed-time changes allow motorists to better anticipate and plan for the reversal. Dynamic reversal provides more efficient traffic flow when over-saturation exists in both directions and there is a need to optimise the time of lane reversal to best advantage in response to demand variations.

Manual reversal

The simplest lane reversal systems consist of the placement of lane delineators between the opposing traffic flows, with tapered lateral transition sections. The delineators are striped poles (sometimes called candy bars) made from hard plastic and placed in sockets drilled and epoxied into the pavement at about 12 m spacing to establish the desired lane configurations. Where sockets cannot be drilled, e.g. on bridge decks, pavement flaps or collapsible delineators may be used.

They are moved 'from one' lane configuration to another, manually, under the protection of a moving vehicle ('shadow' vehicle) travelling in the direction of lane reduction.

Moveable medians

Partially automated lane reversal systems use a moveable median with the assistance of a purpose-built trailer or truck.

One such system uses a specially designed trailer to move a solid rubber median topped with reboundable delineators from one lane to another (Figure 7.1).

Figure 7.1: Solid rubber moveable median

Source: Roads and Traffic Authority (unpublished).

Another type of moveable median consists of short sections of high strength, reinforced concrete blocks pinned together to form a continuous barrier. A purpose-built vehicle picks up the barrier on one side of the vehicle and using a series of rubber rollers (beneath the vehicle) transfers it to the other side. As the vehicle progresses, it places the barrier back onto the road in its alternative position. Figure 7.2 shows such a scheme.

Figure 7.2: Concrete barrier moveable median

Source: Roads and Traffic Authority (unpublished).

Moveable medians may also be fixed in position at one end and remotely controlled, pivoting about the fixed end to place the far end in an alternative position (Figure 7.3). In this case they consist of prefabricated steel segments, articulated so they can assume pre-defined curved alignments. Power modules (electrically powered hydraulic pump/motor sets) are at the far end and optionally also at an intermediate point allowing more complex curved alignments.

Figure 7.3: Remotely controlled moveable median

Source: Roads and Traffic Authority (unpublished).

Remotely controlled, motorised moveable medians of this type are useful in the transition sections approaching a reversible lane section to channel traffic into the desired lane configuration.

Dynamic reversal systems

Dynamic reversal systems usually comprise some form of delineation or separation of opposing traffic flows at the transitions at each end of a reversible lane section to channel traffic into the desired configuration, together with overhead lane control signals to maintain the configuration and VMS and/or CMS at each end to inform and guide the road users. The delineation/separation devices at each end are capable of automation in a fully dynamic system, consisting of remotely switched, internally illuminated pavement markers or remotely controlled moveable medians.

Dynamic reversal of lane direction is made by remotely reconfiguring the approach, then progressively changing the display in the overhead lane control signals. While this can be automatically initiated, for safety reasons it should always be subject to operator's validation. CCTV surveillance will assist here. The operational sequence is then:

1. Close the lane. This may be done in sections between successive gantries to achieve a progressive closure.
2. Wait until no traffic remains in the section.
3. Re-open the lane to traffic in the opposite direction.

Figure 7.4 shows an example of reversible lane management using overhead lane control signals.

Positive designation of which lanes are open and which are closed to traffic in each direction is essential in reversible lane systems that rely on lane control signals. For this reason integrated VSL/LCS systems that rely on a speed limit display to implicitly indicate a lane is open should not be deployed in reversible lane applications unless there is a physical, preferably safety, barrier between the opposing lanes.

Figure 7.4: Dynamic reversible lane control

Source: Queensland Department of Transport and Main Roads (unpublished).

7.2.3 Shoulder Lanes Use

As the name implies, shoulder lane use entails opening the hard shoulder for vehicles (either general purpose or specific vehicles) to use. This in effect adds an additional trafficable lane to the existing trafficable cross-section.

Although not widely used locally, this technique of increasing the capacity of the existing road network is being used in other countries and is considered to be effective in situations such as (Austroads 2007b):

- over short lengths (< 2 km), at key bottleneck locations, in order to ease congestion
- between interchanges, so as to minimise the need for drivers to interact with the mainline traffic flow
- an extension to the off-ramp between two interchanges
- when combined with other tools such as variable speed limits, LUMS and VMS. Typically speed limits are altered to match the new environment (no shoulder) in order to improve safety when hard shoulders are operational. This allows the technique to be used over extended lengths (Austroads 2008).

Austroads (2009a) suggests that shoulder lane use for general traffic could be considered when:

- average vehicle volumes exceed 1800 veh/hour/lane for several hours per day and for each lane
- average travel time is longer than 150% of the free flow travel time for several hours per day
- a high level of traffic demand exists over a specific period (part-time use) or over a 24-hour period (full-time use)
- where the shoulder is suitable as a trafficable lane for vehicles.

Austroads (2009a) provides guidance on key design principles for the application of shoulder lane use.

7.2.4 Tunnel Control Systems

From a traffic operations viewpoint, tunnels require systems for:

- incident management
- lane use management
- tunnel closure.

They also require systems to control ventilation, lighting and communications, and fire and life safety systems, but these are outside the traffic operations domain and are not discussed here.

Incident management

Incident management is critical within tunnels, requiring supporting incident detection, VSL systems and VMS. In major tunnels direct communication with road users is provided by radio rebroadcast systems which must be specifically licensed.

Note that failure of a tunnel ventilation system to maintain the specified air quality is regarded as an incident requiring an established incident management plan. This may involve either limiting the volume of traffic entering the tunnel or temporary closure of the tunnel.

Lane use management

Lane use management systems for major tunnels have the same elements as LUMS for other roads: detection systems, incident detection algorithms and lane control signals. A point of difference is that the lane control signals, where signal positioning and limited height clearance dictate, may comprise traffic signal lanterns showing down-pointing white arrow and red cross aspects (Part 10 of the Guide to Traffic Management) (Austroads 2019d).

Tunnel closure

In the event of a major incident in a tunnel it will usually be necessary to close access to the tunnel. This is achieved by a combination of:

- VMS on the approach to the tunnel
- traffic signals and/or lane control signals in the immediate vicinity of the tunnel portal
- where practicable some form of physical barrier (boom or gate) near the portal.

Tunnel closure may also be required to prevent selected vehicles, e.g. over-height trucks, from entering the tunnel.

Figure 7.5 shows a method employed at the Sydney Harbour Tunnel that has been effective in preventing access by over-height trucks. It comprises a water screen onto which is projected a laser generated display of a Stop sign. The water screen and laser projection are triggered by passage of an over-height vehicle beyond a detection point.

Figure 7.5: Water screen at Sydney Harbour Tunnel

Source: Sydney Harbour Tunnel Company and Laservision (unpublished).

7.3 Variable Speed Limits (VSL)

7.3.1 Introduction

A key principle of the Safe System approach is that there are limits to the amount of force our bodies can tolerate before we are injured (Section 2.2). In a Safe System, when a crash occurs the forces are managed such that they do not lead to death or serious injury. The ability to vary speed limits in response to changes in road safety risk is a valuable tool that can assist with risk management and contribute to safe speeds on the road network.

Variable speed limit (VSL) signs are speed limit signs (either electrical or mechanical) that can be operated to change the speed limit at different times of the day when the road safety risk is elevated, or in response to different traffic, road or weather conditions. They may be:

- applied to roads where there is high pedestrian activity at certain times and potential for significant conflict between pedestrians and motor vehicles (e.g. school zones)

- used on freeways or motorways to improve safety and capacity during times of high traffic demand: refer to the Guide to Smart Motorways (Austroads 2016b)
- used at other locations where adjusting speed limits may improve safety (e.g. in the vicinity of an incident or during adverse weather conditions or at isolated rural intersections to reduce speed limits on the main roadway when there is traffic waiting to enter the main road from a side junction).

VSL systems can be used on their own or in conjunction with a lane use management system. The signs are described in Part 10 of the Guide to Traffic Management (Austroads 2019d).

VSL systems can be used for a range of purposes, including:

- in freeway and motorway management to
  - reduce road crashes
  - provide general speed management during planned incidents such as roadworks or special events
  - reduce flow breakdowns
  - increase motorway efficiency.
- on roads where there is high pedestrian activity and potential for significant conflict between pedestrians and motor vehicles
- on arterial roads subject to reversible lane (tidal flow) management in order to safely accommodate both normal and tidal operation
- tunnels and bridges
- at school zones.

7.3.2 Modes of Operation

Different methods can be used to operate VSL signs (Table 7.2).

Table 7.2: Methods of operating VSL signs

Method	Description
Time-of-day	This approach sets different speed limits for different times of day according to a pre-defined speed table. School speed zones are often operated on a time-of-day approach. The pre-defined timetable is operated and updated based on school term schedules. A VSL system may use software to change a speed limit automatically by time of day based on historical traffic data. This method would be most effective when there is a consistent, well-defined traffic profile that does not change significantly from week to week. Time-of-day can also provide a backup to a more sophisticated VSL algorithm in case of equipment or communication failure.
Dynamic speed limits	This approach aggregates real-time traffic data, incident detection, weather data and other relevant information, and generates dynamic speed limits based on traffic conditions and logic rules. These methods may include such factors as pre-defined speed table, smoothed speed, speed and flow, and other more complex dynamic algorithms. VSL for congestion management (e.g. end of queue management) and incident management often operate using this approach.
Manual intervention	The ability to override algorithms is also an important feature of the VSL algorithm, allowing operators to manually accommodate incidents, maintenance, and tuning errors associated with the algorithms.
Manual control	VSL systems can also be 100% manually controlled by operators or field staff. It is prudent to require authorisation for changes to the sign and to keep record of authorisation for all changes. It is required to log all changes to speed limits. The actual methods for logging speed limits should be in accordance with jurisdictional practices, but may include electronic logging/time stamping or a paper based logging system. This log should be retained for evidentiary purposes, especially for enforcement and safe incident management, traffic congestion, and management of weather related events. This log can also be kept for system evaluation and future research by traffic specialists.

Source: Austroads (2009b).

7.3.3 Implementation in School Zones

The Safe System approach recognises that the chances of incurring serious or fatal injuries in a crash increase dramatically as the impact speed exceeds a certain threshold. For crashes involving pedestrians this threshold is around 30 km/h (ATC 2011).

VSL signs are commonly used in school speed zones, particularly on arterial roads (Figure 7.6). At the current time, general practice is to reduce the speed limit to 40 km/h during designated hours (when activity is highest) on school days only. When the reduced speed limit is in operation it is standard practice for the roundel to flash to indicate a change from normal conditions. Any flashing of the roundel/annulus needs to conform with regulatory and local jurisdiction requirements. In Australia, the annulus/roundel operation is typically in accordance with the requirements of Australian Standard 5156: Electronic Speed Limit Signs which requires the outer most pixel ring to remain on while all other pixel rings flash.

Figure 7.6: Variable speed limit sign for a school zone

Higher speed limit – applies outside of designated school zone hours

Lower speed limit – applies during designated school zone hours

7.3.4 Enforcement

Because of the variable nature of the speed limit displayed, it is essential for enforcement purposes that the control system provides for an accurate record of the display at all times.

In some systems (for example, on the M25 motorway around London, General Holmes Drive in Sydney), the VSL display is coupled with an automated enforcement system (involving cameras, video or fixed, recording licence plate numbers), which detects motorists exceeding the posted speed limit by a predetermined threshold.

7.3.5 Other Considerations

It may be confusing and unsafe if drivers encounter too many different speed zones within a short distance or too many speed limit changes within a VSL zone. For this reason, speed changes should be 'smoothed' to reduce driving stress. The speed limit operation should always follow the principles defined by AS 1742.4. The following principles should also be incorporated into the algorithms that manage VSL operation:

- No sign should change so frequently that a driver sees more than one speed limit change at a single site, except in the case of an emergency (e.g. extreme weather or traffic incident).
- A speed limit buffer should be provided where there is a total reduction in the speed limit of at least 30 km/h.
- In emergency situations, the VSL sign group immediately upstream of the incident site can be set to the safest speed limit. The VSL sign groups further upstream of the first sign group can gradually be reduced to this value in increments of between 10 and 30 km/h as buffer speed signs. The downstream VSL sign groups immediately after the incident can be set back to the normal maximum speed limit (e.g. 100 km/h).

Sign failure should be considered for VSL signs including:

- If a single sign in an array is blank, the speed in the adjacent sign(s) applies; if an entire gantry or set of pole mounted signs is blank, the last speed limit sign applying to that length of road applies according to the Australian Road Rules.
- Drivers should be notified of changes in the maximum speed limit in case of electronic sign failure.
- No repeater black out signs should be installed within the zone to avoid resetting a higher speed limit (note: black out signs post the speed limit when the VSL is not operating, refer to Austroads 2009b).
- Roads and Maritime Services of NSW protocol for sign failure is that if a single sign is blank, the speed on the other pole mounted or overhead mounted sign(s) should also be blank (Roads and Traffic Authority NSW 2004). Other jurisdictions consider it important to allow a single sign at a site to go blank, without blanking other correctly functioning signs at the same chainage points especially during times of speed reduction or display of lane control signals. The option adopted for a particular VSL zone should consider local conditions. VSL signs at the same 'point' on a carriageway including ramps should always display the same speed limits.
- The performance of a VSL sign should be monitored from an operations and maintenance perspective. Real time monitoring represents best practice; however it is acknowledged that this is not always appropriate, especially for rural systems.
- Best practice in the design of the VSL system involves risk management to address specific issues associated with a VSL application (e.g. to maximise the reliability of critical VSL).

Part 10 of the Guide to Traffic Management (Austroads 2019d) provides guidance on VSL sign displays and positioning. For additional VSL considerations, refer to Austroads (2009a and 2009b).

7.4 Co-operative Intelligent Transport Systems

Co-operative Intelligent Transport Systems (C-ITS) facilitate the wireless communication between vehicles and roadside infrastructure. C-ITS enables real-time updates of the road environment; if a hazard or incident is detected by one vehicle it may be communicated to other vehicles in the area, thereby increasing the awareness time beyond what the driver can visualise. Similarly, hazards may be communicated to and from traffic management centres. C-ITS may also aid in the reduction of emissions and increase efficiency by communicating signal sequences between vehicles and traffic signals, and aid in the priority of vehicles such as buses or freight.

C-ITS is defined as communication between the following entities:

- Vehicle-to-vehicle (V2V)
- Vehicle-to-infrastructure (V2I)
- Infrastructure-to-vehicles (I2V).

C-ITS also allows communication between pedestrians, cyclists, traffic management centres and vehicles including trams, buses, trains, and motorcycles. Communication between vehicles (V2V) and between vehicles and infrastructure (V2I) in the C-ITS environment includes peer-to-peer communications (e.g. 5.9 GHz dedicated short range communications) and wide area communications such as cellular communications through the use of telecommunication provider services.

Through the linking of road users with the road environment, C-ITS enables the time and spatial horizon given to vehicles and drivers to be increased beyond what the driver could naturally see. The increased time and spatial horizon enables information about threats, hazards and road conditions to be relayed to the driver potentially earlier than what the driver could have become aware of naturally, enabling Advanced Driver Assistance Systems (ADAS) to implement response systems (depending on what actions the ADAS is designed to undertake) and allowing the driver more time to take appropriate remedial action.

Therefore, the development and orderly deployment of C-ITS applications in Australia has the capacity to achieve these measures:

- reduce the numbers of fatalities and injuries through the introduction of active road safety systems, such as collision avoidance and improved incident response times (clear pathways for emergency vehicles)
- reduce costs associated with road crashes, given that C-ITS has the potential to significantly reduce crashes
- reduce delay times and vehicle operating costs arising from the incidence of congestion
- improve the productivity of infrastructure use, and hence reduce the costs associated with infrastructure provision and management and increase transport system efficiency
- reduce the negative impacts of transport on the environment.

Substantial work has been undertaken internationally on the development of low latency, short range communications for V2V and V2I (Austroads 2014a). Europe and the USA are looking at starting to deploy V2V and V2I from 2015. Japan has already deployed vehicles and roadside infrastructure with some C-ITS functionality. These developments include:

- the Driving Safety Support System (DSSS), which uses and infrared (IR) beacon and dedicated short range communication (DSRC) for stop sign violation avoidance, right-turn collision avoidance, red light violation avoidance, and rear-end collision avoidance.
- Advanced Safety Vehicles which are capable of Cross-Traffic-Turning and Oncoming Vehicle Collision Avoidance System, Inside-Lane-Turning Vehicle Collision Avoidance System.

In addition to V2V and V2I connectivity, C-ITS also caters for the evolution of vehicle-to-business (V2B) connectivity. Examples of current V2B connectivity include telematics and traveller information services utilising wide-area communication such as:

- Transport Certification Australia’s Intelligent Access Program (IAP)
- the provision of routing and congestion information to vehicles via private service operator applications delivered through navigational devices.

7.4.1 Elements of C-ITS

Elements of C-ITS include electronic speed limit signs (or variable speed limit signs), field devices, traveller data collection, traffic signals, and traveller information systems (Austroads 2014a).

Variable speed limit signs

C-ITS can be used to provide both advisory and regulatory speed limit information to vehicles for the purpose of action by the driver or for action by the vehicle through means such as speed limiters. Communicating speed limits to vehicles is aimed at improving speed compliance and awareness.

Speed limit signs have varying levels of dynamics. The speed limit may adjust based on time of day and week, such as in school zones, or more dynamic models may adjust to weather and traffic conditions. Applications of electronic speed limit signs may include:

- incident management
- queue management
- speed control associated with geometric deficiencies
- speed control associated with inclement weather
- roadworks (occupational health and safety)
- reversible lanes
- school speed zones
- shopping zones
- tunnels and bridges.

Higher-level dynamic speed limit signs require more advanced support systems and architecture in order to communicate data to vehicles:

- Timed speed limits may be entered into a database and downloaded by the vehicle, and updated periodically as required.
- Dynamic speed limits will require a data signal and receiver within the vehicle in order to communicate the time and location of the varied speed limit according to the current weather and traffic conditions.

Traveller data collection

Traffic data such as vehicle counts from traffic control systems, travel time data from vehicles and lane occupancy data provide road agencies with insight into traffic conditions of their networks. Data collected from C-ITS equipped vehicles can enrich the set of traffic data available to road agencies.

Travel time data from C-ITS equipped vehicles may be logged historically to assist in the evaluation of network performance and future planning. Real-time travel time data may also be utilised to monitor and communicate environmental dangers such as poor weather conditions, or give warning of major incidents on the roadway which create unusual congestion.

In addition to data collected directly from vehicles, travel time and traffic data may be collected through fixed road infrastructure. This may include technologies such as inductive loop detectors, wireless vehicle detection systems and weigh-in-motion. Some non-intrusive technologies include Bluetooth, microwave radar, closed circuit television and ultrasonic.

Although traffic data collected through infrastructure is highly useful, there is increasing application of probe data obtained through technology such as GPS. Probe data does not require physical installation on the roadside or road surface, as fixed infrastructure does, making it more desirable and versatile for road agencies.

Traffic signals

Integration of traffic signals into C-ITS can improve intersection safety, fuel efficiency and facilitate priorities to selected road users, such as busses. By communicating signal phasing and timing data (SPaT) to vehicles a number of applications can be implemented including (Austroads 2014a):

- intersection safety (where signal phasing is communicated to the vehicle in order to aid prevention of red light running)
- green wave
- energy efficient intersection control
- traffic light optimal speed advisory.

Already there are some applications, such as a public transport priority scheme, which monitor the priority vehicle’s progression along the road network and provides input to the traffic signal control.

Traveller information systems

C-ITS can be used to provide information to drivers in order to assist in their driving task. As with VSL, there is potential to provide traveller information to C-ITS equipped vehicles through cellular communications, radio broadcasts and DSRC.

7.4.2 C-ITS Communication Mediums

The C-ITS platform would use various communication mediums depending on the C-ITS application to be delivered. For example, vehicle-to-vehicle and/or vehicle-to-infrastructure safety applications require low latency, highly reliable and free communication mediums. The primary communication means of these applications would be Dedicated Short Range Communications (DSRC) via the 5.9 GHz radio band. This band is critical for the objectives of C-ITS to be achieved. It is recognised that C-ITS will need to address the interaction and interfacing between 5.9 GHz and other rapidly evolving communication mediums such as cellular networks and private microwave and fibre networks.

7.4.3 Applications of C-ITS

Safety

By communicating information between vehicles via C-ITS within a shared environment, a vehicle is able to have a 360-degree awareness of its environment, beyond what is possible through the use of radar and sensors. Through this awareness, the vehicle is able to inform its operator of hazards and situations that the driver may not be aware of.

Advanced C-ITS safety applications in the future are likely to see further integration with the vehicle's ADAS so that it can pre-arm the vehicle's crash response systems, enabling the vehicle to be more prepared for a crash and thereby reducing its severity.

C-ITS applications align closely with the Safe System by supporting the safe vehicles and safe road users pillars. For applications involving communication with road users it is vital that the human-machine interface is well designed to maximise effectiveness and ensure that users are not overloaded or distracted from critical tasks.

In the future, following integration with other wireless technologies, the C-ITS system could also be extended to other elements of the road system such as bicycles, pedestrians and trains, to enhance the safety of the interactions with vehicles.

Due to the relatively low cost of an original equipment manufacturer (OEM) C-ITS unit in a new vehicle, C-ITS has the potential to deliver affordable safety benefits across the entire vehicle market including the low-end vehicle market, which may have missed out on the safety benefits achieved through other more expensive systems based on radar and cameras. In addition, C-ITS applications have the potential to be deployed as aftermarket devices that may be able to be retrofitted to compatible existing vehicles, enabling the deployment of C-ITS to further extend beyond just those OEM C-ITS equipped vehicles and increase the percentage of C-ITS equipped vehicles on the road. C-ITS may not necessarily replace other vehicle safety systems (such as camera and radar-based technologies) but may be used as an additional technology to enhance the delivery of vehicle safety applications.

Productivity and efficiency

The C-ITS system has the potential to obtain valuable traffic flow information from thousands of equipped vehicles at any particular time. This information can help transport managers monitor and respond to the information provided, so as to better manage the transportation system's performance through adjusting traffic and motorway ramps signals, dispatching emergency services and providing real-time traveller information into the vehicle to reroute traffic around congested locations or incidents. Through acting on the information provided, it is expected that systems and procedures could be developed and implemented in order to help reduce the occurrence and length of flow breakdown on the road network. C-ITS services and applications would assemble real-time vehicle data to develop enhanced congestion maps (far superior to the maps available today due to increased sample size and reduced latency) that would enable vehicles to make better utilisation of the road network, thus improving productivity and efficiency. C-ITS has the potential to offer additional services to both the road user and the road operator. Such services include an automated emergency call service (eCall), an automated vehicle breakdown call service (bCall), improved freight and fleet productivity through improved compliance with regulations enabling route access by higher-productivity vehicles and enhanced logistics, and car park location guidance systems. These would build on existing ITS applications through integration of legacy systems such as Transport Certification Australia's Intelligent Access Program.

Environment

The use of the equipped vehicles as probes will provide exclusive road condition information to support weather warnings, asset management and road repair planning, including dispatch of maintenance crews for emergency works.

Through the provision of productivity and efficiency applications, C-ITS has the potential to reduce emissions by enabling road users to make more informed decisions about their driving habits, which can reduce the environmental impact of their trips. Also, some environmental applications are being investigated that will reduce fuel consumption and emissions by advising vehicles when to switch motors off when waiting at traffic signals.

7.5 Travel Aid and Road User Information

This section provides guidance on traveller information systems in common use in Australia and New Zealand. It focuses particularly on systems directed at the provision of information to road users as part of the traffic operations functions of road agencies.

7.5.1 Road User Information

The purpose of providing road user information is to influence behaviour in one or more of the following ways, aimed at more efficient use of the road network:

- transport mode choice
- route choice
- time-of-travel choice
- driving behaviour.

Table 7.3 summarises the rationale for each of these, and the types of message that may be applicable.

Table 7.3: Influencing road user behaviour

Behaviour	Rationale	Messages
Transport mode choice	Encourage road users to change their mode of transport to a more sustainable mode (e.g. bus, tram, bicycle, higher occupancy vehicle). Provide advice on the benefits of moving to that mode. Advice can be specific to a route or can relate more generally to choosing sustainable transport modes.	Comparative travel times for car and public transport (when favourable to public transport). Absolute travel time for public transport only (for public transport priority routes). Public transport information, such as bus, tram, or train service frequencies, next available bus, tram or train. Park-and-ride directions with or without travel times. Comparative travel times for park-and-ride and car. Availability of parking spaces. Comparative greenhouse gas emissions information for car and public transport.
Route choice	Minimise congestion by encouraging road users to choose routes that are being managed to assist their travel mode. Assist road-based public transport by encouraging general traffic to use routes other than public transport priority routes. When incidents or unusual delays occur on a route, advise road users about alternative routes to reduce impacts on network operation.	Information about incidents or delays on the route, and alternative routes. Travel time along the route. Predicted future travel time along the route. Alternative routes when incidents occur. Travel times on alternative routes.
Time-of-travel choice	The time-of-day that road users choose to travel can result in significantly different travel times. Reduce congestion by spreading the peak road user demand.	Information about incidents or delays on the route. Travel time along the route. Predicted future travel time along the route. Comparisons of travel time by time-of-day.
Driving behaviour	Individual driver behaviours can impact on the efficient operation of a roadway. Driver decisions relating to the choice of traffic lane, the frequency of lane changing, merging, and travel speed can all significantly affect the route capacity.	Lane availability ahead of road user (due to incident, roadworks, congestion). Advisory or optimum travel speed. General messages about lane changing, advance warning of correct lane use, e.g. when changing routes or merging.

With regard to route choice, note that diversion of only a small proportion of traffic from a congested route can result in a significant improvement in overall travel time. For example, Thomas (2005) reported that on the Ile de France freeway network, 6% of traffic diverted on the display on the VMS showed that there was congestion on the network, but if 2% of the drivers altered their route, this could result in a reduction in total travel time of 12%.

7.5.2 Information Delivery Channels

Road users require information at a number of identifiable space-time windows, or decision points. For regular commuters, it may be before departing home or work, to know that traffic conditions are not abnormal. For unfamiliar travellers, it may be preferred routes, traffic information, roadworks in progress and other information to plan their trip. Such information can be described as 'static' information. When conditions change, as a result of incidents, unplanned events or abnormal congestion then, for both familiar and unfamiliar road users, a varying degree of 'dynamic', prescriptive and predictive information is required.

A range of different delivery channels are required to deliver information to meet the range of needs described above. Table 7.4 shows the channels available to disseminate information to road users. Those more commonly used in Australia and New Zealand are further discussed in succeeding sections.

Table 7.4: Information delivery channels

Information	System	Visual dissemination	Audio dissemination
Pre-trip	Computer	Internet Electronic bulletin board Videotext, kiosk, email	Internet broadcasts
	Telephone	Internet phone (GPRS and 3G phones)	Traveller advisory telephone service Pager Mobile phone (call centre, voice and SMS)
	Television, radio	Free to air, teletext Cable, interactive	Radio broadcast
En route	In-vehicle systems	In-vehicle navigation RDS-TMC	Radio broadcast Hands-free mobile phone Automated announcement systems (public transport)
	Roadside information systems	Kiosks Static road signage Travel time signs Variable message signs (VMS)	–
	Personal based systems	Personal digital assistants (PDAs) Pagers, mobile phones (SMS, WAP, GPRS)	Mobile phone

7.5.3 Pre-trip Information

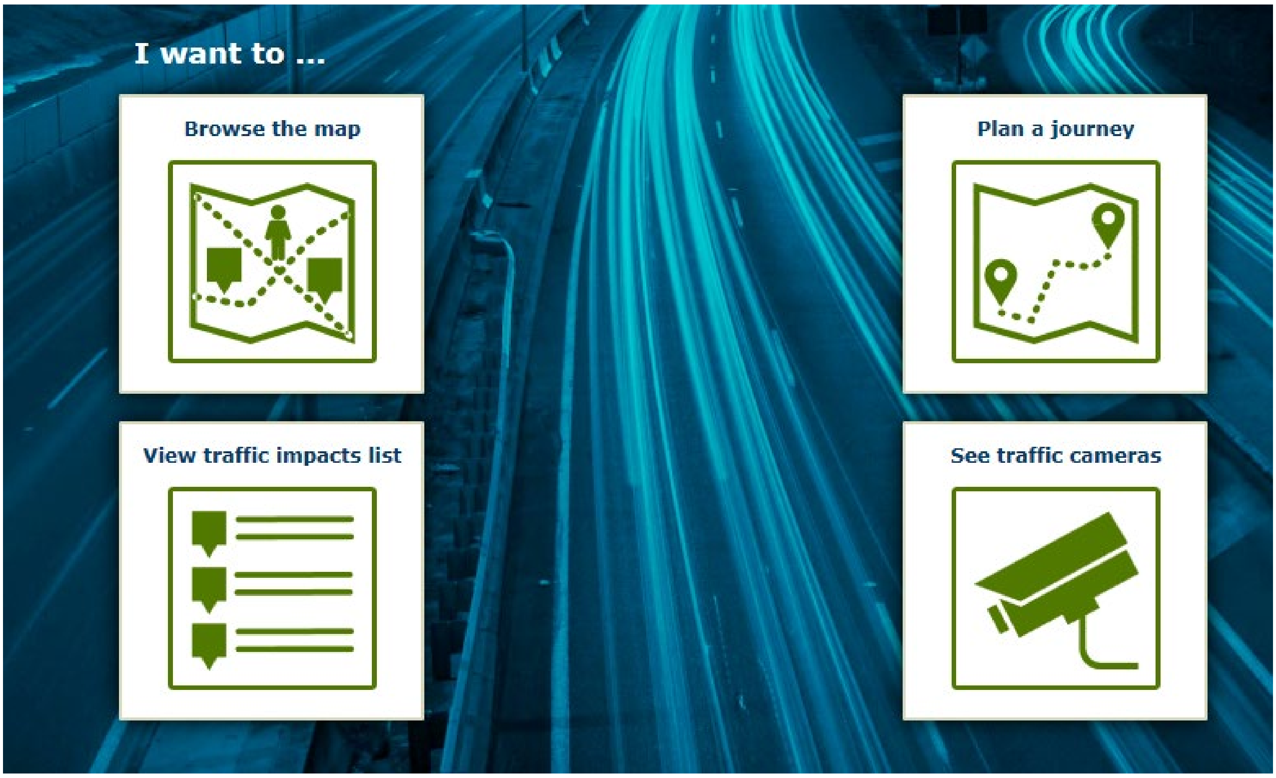
Internet

Pre-trip information on road agency websites provide travellers with information to assist choices in travel mode, route choice, departure time and even whether to make the trip. Information provided may include:

- traffic incidents
- roadworks
- colour coded congestion levels
- travel times
- traffic arrangements for special events
- live web camera images.

Figure 7.7 provides an example showing the range of information that may be offered by such websites.

Figure 7.7: Traffic website



Source: Queensland Department of Transport and Main Roads (2016).

Telephone

Pre-trip delivery of traffic information to road users by telephone is available via several channels.

In Australia and New Zealand most road agencies provide telephone dial-up services for road condition, traffic incident and special event information. These are complementary to traffic incident reporting lines operated by many authorities, connecting road users direct to operators at the traffic management centre for the purpose of reporting abnormal traffic conditions and incidents.

Internet services above can also be accessed via internet-capable mobile phones.

Commercial mobile phone applications are available in some cities to facilitate obtaining traveller information. Subscription services also offer SMS text messages alerting road users to roadworks and current incidents based on personalised user and route profiles, e.g. current alerts can be sent at a specified time-of-day for a specified route. This information can also be provided by email.

Radio broadcast

Traffic information broadcast by radio typically includes roadworks, incident reports and abnormal congestion. The information, announced either direct by the radio station announcer or by ‘cross’ to a specialist traffic information provider, is often sourced from the road agency but may be supplemented by information from other sources.

Television

Traffic information on free-to-air television is usually limited to short segments on early morning television. These are tailored to very short timeframes, typically less than a minute, focused on one or two routes and/or major incidents.

Scope exists with digital TV for a dedicated traffic channel as exists in some other countries, but at the time of writing such a channel is not operating in Australia or New Zealand.

7.5.4 En Route Information

Variable message signs

Variable message signs (VMS) are widely used to provide road users with information about road and traffic conditions. VMS messages are electronically generated and can be changed to display predefined or free text information, figures or symbols. They have the ability to display a large range of individual messages for the purpose of directing, warning or guiding road users. More detailed information on VMS and their underlying technologies can be found in Part 10 of the Guide to Traffic Management (Austroads 2019d).

This section gives guidance on the use of VMS for the provision of **traffic information**. VMS technology can also be used for **traffic control** purposes; examples include lane control signals and variable speed limit signs. Other applications of VMS are discussed in Part 10 of the Guide to Traffic Management (Austroads 2019d).

VMS may be used as individual signs to address a particular issue, or as part of a system to manage traffic along a road or within an area. A common systemic use is for the management of traffic during incidents on high volume urban motorways or on the arterial road network. The need for VMS is typically determined on a case-by-case need of driver information on a route. This will be influenced by factors such as:

- availability, utilisation and driver understanding of alternative routes
- congestion influences on a subject route
- traffic characteristics on a subject route
- need to provide specific driver information (e.g. travel time) or support other management tools (e.g. identify reason for VSL speed reduction).

A VMS may be a permanent sign or a temporary sign mounted on a trailer or vehicle to meet a short-term need.

Whatever the use of a VMS the same issues of sign conspicuity, legibility and comprehension as for static signs, compounded by the VMS capability of spreading a message across more than one screen (or frame), must be addressed.

Guidelines to achieve the required levels of conspicuity, legibility and comprehension are given in Part 10 of the Guide to Traffic Management (Austroads 2019d) on the following:

- sign dimensions and other physical characteristics
- legibility
- types of messages and symbols
- message content and format
- message load and exposure time
- location and spacing.

The guidelines include recommended (Austroads 2019d):

- abbreviations
- message statements, comprising
  - problem statements
  - location statements
  - effect statements
  - attention statements
  - action statements
  - time and date statements
- generic message sets.

VMS operation can be manual, semi-automatic or fully automatic.

Manual operation relies primarily on a pre-prepared set of generic messages; free text may also be used.

Most existing systems are manually operated, the operator being aided by computer outputs such as travel times on the competing routes, or simply by other data from the field (such as video images), or by pre-determined strategies designed off-line for a given number of situations. These systems cannot generally handle complex situations such as incidents in a grid motorway network, or multiple incident situations, and are often unable to give an updated strategy, once the first one is implemented. They also generally do not include forecasts (of the demand and of the impact of the current strategy), so they are far from producing an 'optimal' strategy, and they can even produce situations worse than a 'do-nothing' strategy (due to risk of creating over-diversion).

Semi-automatic operation utilises lane occupancy detectors or closed-circuit television (CCTV) cameras that may be linked to alarms to provide warning of an incident and to recommend specific messages for implementation by a traffic management centre operator.

An example of semi-automatic operation is the wide area algorithmic response (WAAR) application implemented in New South Wales. This offers the operator an incident response somewhere between free text manual settings of VMS (slow to implement across many VMS) and the very targeted VMS settings contained within a pre-defined strategic plan.

When the operator declares an incident on the network, WAAR 'walks' upstream from that incident location (on all possible paths) and identifies VMS which could be used to advise of the incident. The distance it walks is configurable but also influenced by the incident type/severity (i.e. it looks further afield for the bigger incidents). Once all VMS have been identified, the application then groups the VMS according to size and offers the operator a selection of fairly generic messages for these VMS groups. These can then be simply and quickly set en masse as the first part of the response. As more specifics about the incident are made available to the operators, they can then supplement the WAAR with a plan and/or some more specific messages on selected VMS.

In Europe some systems, such as MOLA (UK) or VISUM-online (Germany), are able to simulate the impact of a set of possible strategies designed off-line (generally two strategies) in order to help the operator to choose the best one.

Fully automated systems require the integration of incident detection systems with message selection and deployment for the management of incidents, congestion and the impact of adverse weather conditions. For a large network they can be time consuming to develop and maintain across all possible incident locations, covering all contingencies.

One system, OPERA (France), automatically generated guidance strategies using forecasts and a real-time expert system, thereby adjusting itself to current traffic patterns and their forecasts. Benefits of up to a 50% reduction in time wasted due to incident occurrence were reported (World Road Association 2003).

From an operational point of view, and because VMS can be used for different purposes, it is important to establish priorities for their use. For example the following is a suggested descending order of priority based on road safety and traffic flow considerations (Queensland Department of Main Roads 2009):

- accidents/incidents
- congestion
- roadwork
- weather related conditions
- parking guidance
- special events
- road safety messages
- community benefit messages
- general transportation messages.

The last three applications can be considered as filler or standby messages, which may only be displayed if considered useful and appropriate by the relevant jurisdiction. Special events can fall into this category or may be an incident in their own right. Road agency VMS installations should not be used for commercial advertising under any circumstances. It is important that the highest relevant priority message be displayed. This requires the ongoing monitoring of conditions and incidents. If a high priority message would be appropriate, it will bring VMS into disrepute if a low priority message is displayed. Under these circumstances it would be better for no message to be displayed.

The major benefit of VMS is that information can be conveyed to drivers en route in order for them to make more informed decisions on their chosen route and reduce travel time. The VMS system can also be utilised to highlight hazardous conditions and therefore can aid in reducing accidents. Austroads (2003) in its review of the benefits of ITS demonstrated that VMS have varying degrees of effectiveness at diverting traffic from incident routes which can result in varying degrees of travel time savings arising from those incidents. A literature review in Austroads (2007g) reported savings in (average network) travel times ranging from 2% to 4% arising from widespread implementation of VMS.

An automatic VMS system can have a quick response time, from the time of the incident being detected to a message relaying the situation to the driving public being displayed. This can result in possibly reducing further congestion by relaying information to drivers and giving them a chance to divert from their route. A fully automatic VMS system also needs minimal human interaction before implementing the message.

A possible disadvantage of the VMS application is that it may result in a higher diversion rate than the surrounding road network can handle, potentially resulting in congestion on the surrounding road network (Chatterjee et al. 2000). The use of VMS should be carefully considered in the light of the likely impact of diverting traffic onto a possibly lower capacity network. Eves (2005) reported that, depending on the severity of the incident and the time taken to clear the incident scene, traffic operations managers found in hindsight that it was often better not to divert.

Travel time signs

The travel time sign is a particular type of VMS providing travel time estimates directly to motorists on freeways and motorways. A system of these signs has been installed in Melbourne on the Monash, West Gate, Tullamarine and Eastern Freeways (Figure 7.8). It provides accurate, real-time information on travel times and colour-coded congestion levels along the freeway corridor. The colour-coded congestion levels help drivers quickly appreciate traffic conditions in advance. Commentary 18 describes the underlying detection system and travel time estimation process.

[see Commentary 12]

By providing drivers with accurate real-time estimates of travel time, the signs provide an opportunity for drivers to make an informed route choice. The decision whether to divert or not in response to the travel time information is left to the individual drivers, so the risk of over-diversion discussed above is reduced.

Figure 7.8: Travel time VMS – Melbourne's Drive Time system

Source: VicRoads (unpublished).

In-vehicle navigation systems

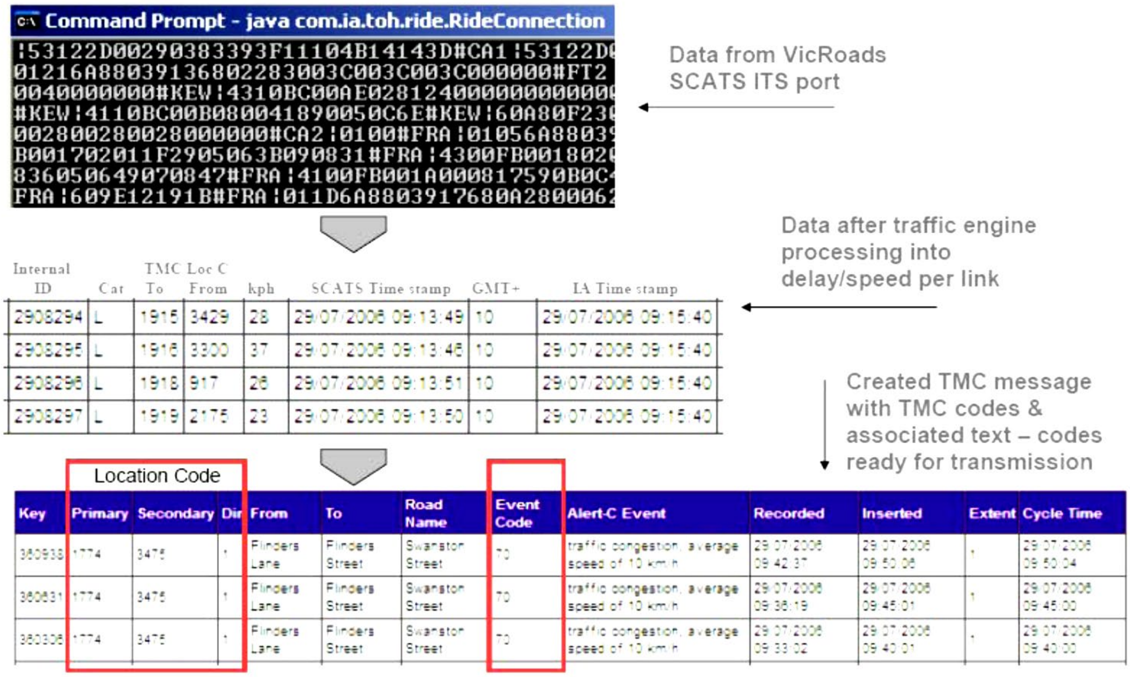
In-vehicle navigation systems use global positioning systems (GPS) technology along with digital maps to assist drivers to navigate the road network. Compatible navigation systems can overlay the map information with traffic information delivered to the navigation unit by RDS-TMC (Radio Data System – Traffic Message Channel) technology on a broadcast FM sub-carrier. RDS is the communications standard from the European Broadcasting Union for sending small amounts of digital information using conventional FM radio broadcasts. TMC refers to the TMC Alert-C coding standard for traffic information and location, fully described in ISO Standard 14819. The location tables are integrated into the digital maps provided by navigation system suppliers, enabling traffic information to be displayed at its correct location on the maps.

Information delivered to RDS-TMC compatible navigation systems may include roadworks, incidents and unusual congestion.

Depending on the service provided and the individual navigation system, alerts may be presented by voice synthesis, graphics or by automatic re-routing around the incident.

A recently commenced service takes real-time SCATS and STREAMS data from road agencies (under commercial agreement) and uses this in a travel time model to estimate travel times and delays. Congestion alerts and travel time and delay estimates are then delivered to road users via RDS-TMC (Intelematics Australia 2011). Figure 7.9 illustrates the stages of data processing involved. Figure 7.10 shows the in-vehicle display.

Figure 7.9: SCATS data processed for RDS-TMC congestion alerts



Source: Austroads (2007h).

Figure 7.10: Navigation system with RDS-TMC congestion and delay data

Source: VicRoads (unpublished).

Traffic information encoded for RDS-TMC can also be formatted in extensible mark-up language (XML) for delivery via internet applications.

Telephone and radio

The telephone and radio delivery channels can also deliver the same traffic information in-vehicle, en route.

8. Systems and Procedures for Smart Motorways

'Smart motorways' is the term used to describe urban motorways that have intelligent information, communications and control systems incorporated in and alongside the road. The national smart motorways initiative includes the implementation of an integrated package of intelligent transport systems (ITS) tools. These include coordinated on-ramp signalling, variable speed limits, lane control, incident detection and traffic flow data, traveller information and closed circuit television surveillance. Smart motorways have the potential to improve efficiency and safety.

Full guidance on smart motorways is in the Guide to Smart Motorways (AGSM) (Austroads 2016b). The Guide covers:

- benefits
- elements including intelligence, traveller information, control, and systems and infrastructure
- planning and design
- principles and analysis of motorway flow
- selection and warrants for smart motorway elements
- geometric elements and capacity analysis
- foundation infrastructure
- network intelligence
- roadside traveller information
- coordinated ramp metering
- lane use management (including variable speed limits)
- provision of emergency lanes
- arterial road and motorway interface management
- other considerations, including
  - localised ITS safety applications
  - tunnel traffic management
  - compliance and enforcement
  - system performance management
  - motorway performance evaluation
  - emerging technologies.

This section provides general information on smart motorways and focusses on the operational aspects at a high level.

8.1 Smart Motorway Overview

8.1.1 Operational Objectives

The operational objectives for smart motorways are to provide integrated traffic management that:

- provides safe mobility; i.e. maximises throughput at a high level of safety by minimising the possibility of flow breakdown and congestion
- provides travel time reliability by reducing variability from day to day
- provides traveller information to inform motorists of traffic conditions on the motorway
- provides integrated and effective management of traffic during incidents with lane use and speed control in the highest priority sections of the route
- manages vehicle speed and speed differential between vehicles to improve safety during periods of congestion or queuing
- provides integration with arterial road operation to optimise operation of the overall road network (motorway and other arterial roads).

Smart motorway projects are typically driven by requirements for capacity improvement; however, they have potential for significant safety benefits. Regardless of the project's drivers, the design, operation and maintenance of smart motorways should apply the principles and concepts of the Safe System approach (Austroads, 2016b).

The systems and procedures for Smart Motorways are closely aligned will all pillars of the Safe System. For example:

- Lane use management systems (LUMS) and ramp metering contribute to safe roads
- Variable speed limit (VSL) signs promote safe speeds
- Cooperative intelligent transport systems (C-ITS) contribute to safe vehicles
- Variable message signs (VMS) contribute to safe users.

In addition, a function of incident detection and managements systems is to provide rapid access by emergency services to critical incidents. The World Health Organisation (2016) recognises post-crash response as the fifth pillar of the Safe System. Early treatment of vehicle occupants or road workers who are injured in crashes ensures that the severity of injuries is minimised and increases the chances of survival.

8.1.2 Elements of a Smart Motorway

The various elements of smart motorways can be classified by their functional purpose comprising intelligence, control or information (Table 8.1).

Table 8.1: Smart motorway elements classified by function

Intelligence	Control	Information
Vehicle detection equipment CCTV cameras Incident detection: • image processing systems • traffic data algorithms Environmental monitoring equipment: • weather • noise • emissions Travel time calculation equipment	Coordinated ramp signalling (CRS) Variable speed limit signs (VSL/VSLS) Lane use management system (LUMS)	Motorway variable message sign (VMS) Arterial road VMS Non-roadside information sources: • radio • in-car systems • websites/social media • CCTV on website • smart phone/smart TV apps

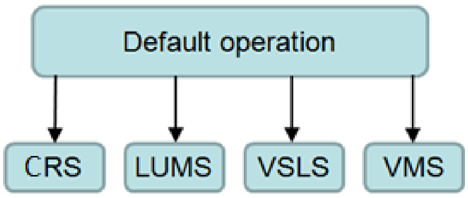
Smart motorway operation relies on the integration of the three primary functions of intelligence, control and information. The intelligence function, including traffic data collection, is the foundation of the smart motorway, informing the control and information functions as well as performance monitoring. Control functions use the information from the intelligence function to optimise motorway performance, maximising safety, reliability and capacity. The information function assists road users with making informed decisions about their travel, for example, route choice and travel time. Field provision of information is particularly important during unusual conditions such as incidents.

8.1.3 Hierarchy of Sub-systems

Historically, separate stand-alone systems have been developed for motorway traffic management, i.e. separate VMS, VSL, travel time, ramp metering etc. However, the sub-systems within the smart motorway system are integrated to the extent that management and interaction is essential. Even though the hierarchy of sub-systems may change according to the circumstances, the sub-systems are still inter-dependent in the way they operate. Without integration the operators would be faced with a significant challenge due to the complexity of the interaction required, particularly during an incident.

The hierarchy of sub-systems during default (normal) operation is shown in Figure 8.1. Default operation occurs when there are no incidents and the system is safely optimising throughput and travel speed.

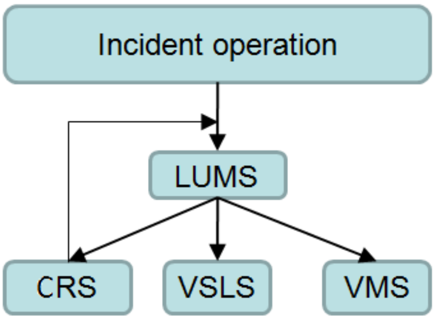
Figure 8.1: Hierarchy of sub-systems under default (normal) traffic conditions



Source: ARRB Group (2012a).

During an incident, the lane use management system (LUMS) becomes the dominant sub-system to control lane use and speed limits as shown in the hierarchy (Figure 8.2). If an incident involves a crash in which a road user is injured, priority should be given to facilitating access to the site by emergency services so that the treatment of injuries can begin as early as possible.

Figure 8.2: Hierarchy of sub-systems during an incident



Source: ARRB Group (2012a).

In either mode of operation, the management system provides automated operation that works within pre-defined rules, generally with minimal operator input unless override is necessary.

8.2 Network Intelligence

The key to effective management of a motorway is reliable and accurate traffic data at appropriate locations. The traffic detection system needs to be dependable to obtain lane-level information, such as volume, speed, occupancy and vehicle classification, for a range of uses.

Real-time data on traffic conditions is essential for the effective dynamic management of motorway flow as it enables:

- proactive management of the motorway 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.

For flow-optimising ramp control algorithms, key traffic data required, preferably lane by lane, includes:

- occupancy (as a proxy for density) – the critical input for mainline control
- vehicle counts and speeds – secondary measures for ramp demand/queue estimation
- vehicle classification – desirable to support occupancy estimations.

This data is also required for VSL applications (i.e. for queue protection, congestion management and flow control) and automatic incident detection. Speed can be used for calculation of travel times to disseminate via real-time traveller information.

Detectors are located on the mainline, entry/exit ramps and upstream arterials, if required. Detector placement is primarily determined by the varying requirements of the real-time (automatic) algorithms for smart motorway control, information and intelligence functions. Additional needs for historical data to inform network performance reporting and planning activities should also be considered.

8.3 Roadside Traveller Information

Roadside electronic signs that display electronically generated messages are an important element of a smart motorway in order to give timely and relevant regulatory, warning and advisory or tactical information to road users, both on approach to the motorway and when travelling on the mainline. This is achieved through variable display of messages related to current and future road and traffic conditions, including travel times, for downstream motorway sections.

Roadside electronic signs should form part of an overall traveller information strategy for the motorway and arterial road network that also incorporates non-roadside traveller information sources, such as in-vehicle and mobile applications.

Traveller information that is delivered in an appropriate manner will aid decision making and reduce driver stress. This supports the safe user pillar of the Safe System. Information provided to drivers must be in a form that is clear, unambiguous and timely. Messages that are complex or delivered at a time when a driver is already subject to a heavy workload can be distracting and impact on critical driving tasks.

8.3.1 Types of Electronic Roadside Signs

There are two main types of permanent electronic roadside signs deployed to support smart motorway operation; mainline VMS and arterial road VMS, as outlined below:

- Mainline variable message signs (VMS) are multi-purpose, full matrix signs that can display a variety of message types, including text and pictograms. VMS are installed on the motorway mainline in advance of key decision points (i.e. major exits/interchanges).
- Arterial road VMS may be installed to provide advance motorway condition information, to enable improved route choice prior to entering the motorway. This is particularly important when the motorway is congested or affected by an incident, and there are alternative arterial routes with a shorter overall travel time to the same destination.

Permanent VMS may be used to address localised performance issues on a motorway or to deliver messages to individual at-risk vehicles. For example, weather warning systems, heavy vehicle speed warning on curved entry ramps and over-height vehicle warning on approach to tunnels and other low clearance structures. Portable/temporary VMS are used for incident, road works and special-event management.

Historically, purpose-built, dedicated travel time signs have also been used on motorways and arterial roads. These signs comprise a standard retroreflective static sign with embedded electronic components that are used to display motorway travel times and/or colour-coded motorway condition information, such as illustrated in Figure 8.3. These signs have been referred to as motorway condition information signs, trip information signs, drive time signs and trip condition signs.

Figure 8.3: Examples of dedicated drive time signs (left and centre) and motorway condition signs (right) in Victoria

Source: Austroads (2016b).

8.3.2 Message Types and Priorities

There are a variety of different message types that may be displayed on a VMS as part of smart motorway operations. Typically, the default message type is estimated travel times to significant downstream destinations including colour-coded motorway condition information. Other message types (in order of priority) include:

1. current traffic incident or event (i.e. hazard warning)
2. community safety (i.e. emergency alerts)
3. planned (future) road works/events
4. campaign/promotion (i.e. relating to safety, congestion or accessibility).

The subsequent guidance in this section refers to the priority numbering listed above. However, if travel time messages are not displayed as default, then they would be third priority (i.e. after community safety and before planned works/events).

The primary purpose of VMS is to display real-time information relevant to a road user's current journey. Messages relating to safety or traffic flow at a particular location (priority 1 and 2 messages) take precedence over those providing less critical information (priority 3 and 4 messages).

Arterial road VMS located at motorway interchanges would generally not display priority 3 planned works/events and priority 4 campaign/promotion messages.

8.3.3 VMS Operation

Message display and approvals

Approved generic message sets should be created for each message type. Approval procedures may be required to govern the appropriate selection and display of different message types. Different message types may require approval by different responsible officers within the agency. In particular, there should be an appropriate delegation of approval for displaying non-standard messages or messages outside defined priority levels.

New message structures for priority 3 planned works/events messages and priority 4 campaign/promotion messages should always be pre-approved prior to display.

Types of control

VMS may be controlled in the following modes of operation:

- **Manual input**

  This involves manual operator input of pre-prepared messages from a standard message library, with spaces for context-specific information, such as in relation to location and time and date information.

  The operator may receive an automatic alert from the system in relation to the need for a change in VMS message display (i.e. from automatic incident detection and environmental monitoring technologies) or manually identify a problem via CCTV cameras or from feedback from operational partners.

  Use of free text messages should generally be minimised, since there is risk of human error which may lead to an inappropriate message.

- **Automatic**

  Fully automated updates to smart motorway VMS generally only apply to travel time and motorway condition messages, which are commonly calculated using algorithms based on data from vehicle detectors or other sources.

  Operators should be able to select the option to display or approve a travel time message (i.e. prioritise over other message types), or to override the decision to display a travel time message due to other higher message priorities.

- **Semi-automatic**

  The motorway system should be capable of 'information only' and 'operator assist' modes. In operator assist mode, the system will provide an automated alert based on a change in detected motorway condition (such as an incident, congestion or adverse weather as detected by data from vehicle detectors, CCTV or weather detectors) and recommend an appropriate response, which may include updates to VMS message displays. The operator is then required to manually modify or approve the response plan prior to implementation.

  The proposed response may be based on a pre-defined response plan (see below), or through an algorithm-based system such as a 'wide area algorithmic response' application.

  In such an application, the algorithm 'walks' upstream of an incident location on all possible paths to identify which VMS should be used to advise of the incident and what message options (from a generic message set) could be displayed. The distance it walks is configurable but also influenced by incident type/severity (e.g. it looks further afield for bigger incidents). An initial message plan can be implemented reasonably quickly by the operator from the algorithm recommendations. As more specifics about the incident are known, then the operator can update relevant VMS with more targeted/relevant messages.

- **Pre-defined response plans**

  These comprise special-purpose plans for display of messages on consecutive VMS downstream of an incident/event. Plans may be developed as part of an incident response plan or traffic management plan for an event. The plans may also provide integrated responses for other smart motorway elements, such as displays for LUMS signs.

  The plans would usually be used to pre-populate the smart motorway schematic to illustrate the proposed sign displays. The operator can then review, edit and approve prior to implementation (i.e. semi-automatic mode).

Operators should be able to manually reprioritise, stop/remove and re-start active message plans on VMS at any time to meet the network operating need.

8.4 Ramp Metering

Ramp metering systems regulate traffic into the motorway at a rate that the motorway can handle in accordance with performance objectives. Ramp metering is the control of traffic entering a freeway or motorway by means of traffic signals on the entry ramps. The performance of the motorway is optimised by maintaining mainline flows at operational capacities during peak periods. The principal actions of ramp metering are:

- The metering of vehicles entering a motorway from an entry ramp to disperse platoons of merging vehicles to achieve an evenly distributed flow of traffic into the merge area.
- Managing ramp entry flows such that mainline traffic flows do not exceed their operational capacities particularly at bottlenecks, thereby preventing transition to unstable flows. This is achieved by establishing and maintaining critical occupancy through the bottleneck sections of the mainline.

Refer to Part 4C of the Guide to Road Design (Austroads 2015b) for guidance on the geometric layout and design of metered ramps.

8.4.1 Ramp Meter Control Fundamentals

Simplistically, the control logic of ramp meters manages the inflow so that the downstream capacity is not exceeded. If the downstream capacity is exceeded, flow breakdown occurs and overall performance suffers. The key objective of control is to minimise the probability of flow breakdown on the mainline subject to back of queue or on-ramp waiting time constraints.

To effectively meter entry ramp flows so that speeds and throughput on the mainline are optimised, the ramp meter system must incorporate a technically effective algorithm that establishes and maintains critical occupancy. For a more detailed discussion on the theory behind ramp metering refer to Part 2 of the Guide to Traffic Management (Austroads 2015a).

Critical density is maintained by metering the number of vehicles entering the bottleneck through restricting the entry ramps downstream of the bottleneck. This is achieved by signals at the entry ramps.

In best practice ramp metering systems, it is crucial that the control algorithm can establish and maintain critical density to ensure that maximum operational capacity flows are maintained. Note that occupancy is used instead of density, since density could not be readily measured by detectors.

If ramp metering logic is too permissive, allowing more vehicles to enter the bottleneck, the occupancy is increased and the probability of flow breakdown is increased. If the metering is too restrictive then the mainline is underutilised and causes longer queues and wait times on the ramp. The back of queues on entry ramps may also extend beyond the ramp and hinder through movements on the arterials. Only by maintaining critical occupancy can maximum mainline throughput be achieved.

8.4.2 Local and Coordinated Control

Ramp meters may operate under local control or coordinated control. Isolated ramp signals without connection to other upstream ramp signals operate under local control. Coordinated control incorporates a group of ramps. Coordinated control optimises occupancy at a bottleneck by managing up to six or more downstream entry ramps.

Local control may be appropriate where 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 motorway is nearing capacity.

Local control for isolated ramp metering installations may be effective in providing reductions in merging problems and improvement of motorway 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
  - this may result in earlier initiation of ramp queue override actions and premature flow breakdown
  - 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.
- It is unlikely to be able to maintain optimum motorway throughput if there is congestion related to other bottlenecks along the route.

For the above reasons, local ramp control is generally not recommended for heavily trafficked motorways where a number of entry demands need to be managed or where flow breakdown may occur at a number of locations.

A coordinated system is generally recommended, however local ramp meter control may be appropriate if:

- congestion and flow breakdown is localised, caused only by traffic merging onto the motorway from one particular entry ramp
- the bottleneck can be effectively managed within the storage limitations of the one entry ramp
- there will not be diversion to a neighbouring ramp.

With coordinated control the ramps are grouped into a manageable number of ramps that can operate together as a control system when traffic conditions require coordination. Within a coordinated group, bottlenecks could occur at many locations including each entry ramp merge and other locations of restricted capacity. The management and control of traffic flow along a length of motorway usually requires metering at all points where traffic enters the motorway. This may include:

- entry ramps with merging traffic
- entry ramps leading to an add lane
- motorway-to-motorway ramps or metering of upstream ramps on the intersecting motorway
- the start of the motorway.

8.4.3 Fixed-time and Dynamic Operation

Ramp meters can operate according to a fixed-time or dynamic basis. Dynamic ramp meter systems dynamically switch the signals on and off as well as alter the metering rate based on the traffic flows along the freeway and ramps. This requires data to be collected on the traffic flow conditions of the freeway. If data collection systems fail the system may default to a fixed-time cycle. 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.
- Automated response to freeway conditions by continually adjusting 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.
- 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.

Fixed-time ramp signals use metering rates that are based on historical general traffic flow conditions during the time when the ramp signals will be in operation. The metering rate does not alter due to changing traffic flow conditions on the main freeway carriageways. Fixed-time ramp metering operation generally switches on according to time-of-day settings and then uses a fixed-time signal cycle. 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 motorway flow conditions. This form of operation can provide some benefit to mainline flow but has limited effectiveness in preventing flow breakdown and optimising motorway throughput. Furthermore, the ability of fixed-time operation to adapt to changing flows on a ramp or manage ramp queues is limited and there may be times when the signals are switched on when control is not necessary.

8.4.4 Managing Ramp Demands

At times during ramp metering operation, the traffic demand on some ramps may not be satisfied. This could occur during the peak hour when mainline flows are at their highest such that the metering is at its most restrictive. At the same time, arrival flow on the ramp may also be at its peak and be greater than the maximum permissible metering rate. The result is residual queuing on the ramp which may overspill onto the adjoining arterial roads if inadequate storage is provided in design.

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. 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.

8.4.5 Managing Heavy Congestion and Incidents

While flow breakdown is generally prevented, or at least delayed on smart motorways, when it 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 motorway congestion include:

- Insufficient control of entry flows – due to no control at the entry of the motorway or some entry ramps not being metered, such as a high-demand ramp from another intersecting motorway.
- Access control strategies or policies that lead to excessive demand – such as ramps with free-flow priority access lanes or a queue management strategy that increases the metering rate for vehicles from a ramp when queues extend onto the arterial road.
- An incident on the motorway – forces the closure of at least one lane, effectively reducing the capacity of the motorway.

Management of heavy congestion and incidents requires an integrated approach which focuses on the following complementary actions:

- Management of entry flows to assist in flow recovery – arrival flows at the congested bottleneck or incident site are reduced through restrictive metering of ramps upstream as an automated response to detection of the congestion. The restrictive metering, along with the provision of traveller information on the arterial roads informing drivers of increased travel times on the motorway, also assists in diverting traffic from the motorway.
- Closing entry ramps and/or the motorway – in some situations, managing an incident may also include closing ramps or the motorway upstream of the incident.
- Traffic diversion by providing traveller information – some motorists will use an alternative route if travel advice is provided in one or more of these forms:
  - real-time driver information signs on the arterial road prior to the motorway entrance
  - mainline VMS to encourage motorists to leave the motorway before reaching the congested section
  - traffic condition reports from radio stations, particularly during peak periods.

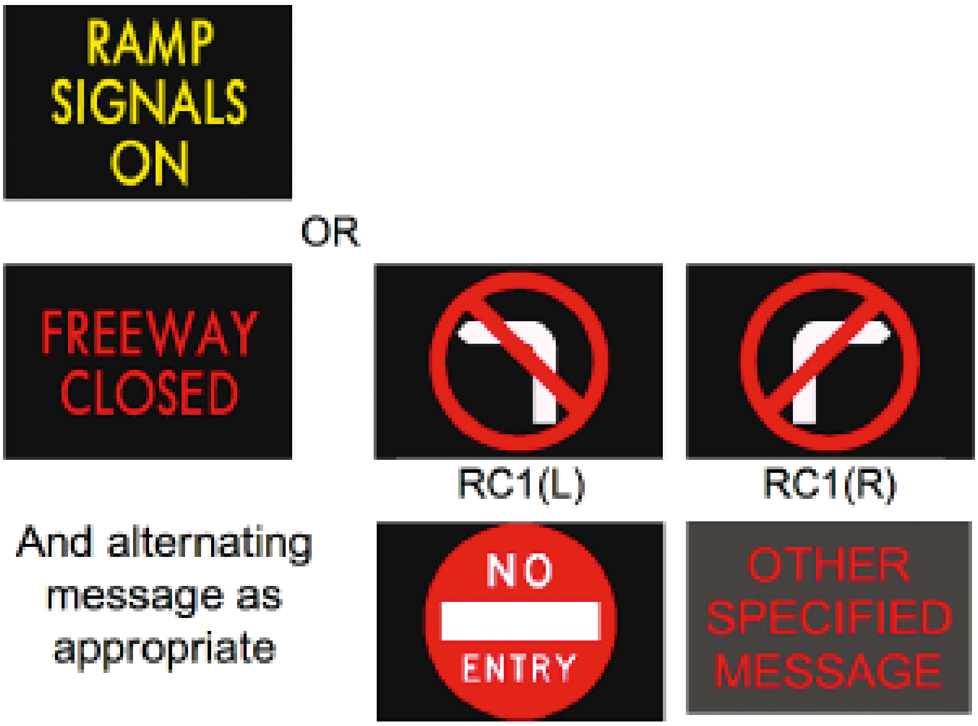
In the event of an incident involving injuries to road users or road workers, priority for the management of ramps must be to facilitate access to the incident site by emergency services so that the treatment of injuries can commence as early as possible.

8.4.6 Electronic Ramp Control Signs

Electronic ramp control signs associated with ramp meter operation are as follows:

- *Warning and regulatory signs on approaches* – provided on the approaches to the arterial/entry ramp intersection to face traffic turning onto the ramp. In addition to indicating if the signals are in operation, they can also be activated to indicate the ramp is closed as part of motorway incident management as shown in Figure 8.4.

Figure 8.4: Warning and regulatory signs on approaches



Source: VicRoads (2013b).

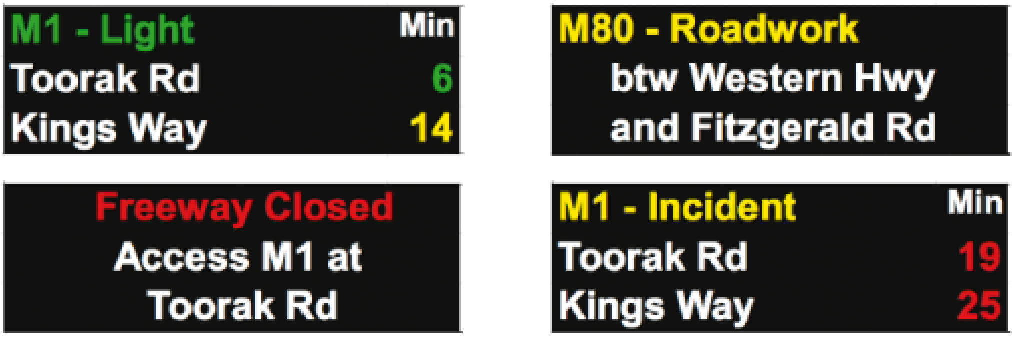
- *Warning signs on entry ramp* – these signs are used on entry ramps for situations where there is restricted sight distance to the ramp signals. They indicate that signals are ahead and alert drivers of the need to stop when the signals are in operation. Figure 8.5 shows such warning signs with the electronic sign alternating the messages 'ramp signals on' and 'prepare to stop'.

Figure 8.5: Warning signs on entry ramp

Source: ARRB Group (2012b).

- *Arterial road VMS* – these signs may be four-colour full matrix variable message signs used to display motorway travel times, including ramp delay, as well as information about incidents, roadwork and motorway or ramp closure. These signs enable drivers to make alternative route choices before entering the motorway. They are located on the arterial road in advance of the left and right-turn lanes at the ramp interchange. Where the interchange is close to a fork in the motorway, such that there are two downstream routes, two of these signs should be provided, one for each route. Figure 8.6 illustrates a range of real-time traveller information messages that can be provided.

Figure 8.6: Messages on an advance motorway condition information sign



Source: VicRoads (2013b).

8.4.7 CCTV Cameras

CCTV cameras are used to monitor the motorway, including ramps and adjacent arterials. A camera located at the interchange near the ramp entrance can provide the best coverage:

- of the arterial road approaches
- along the full length of the ramp
- at the motorway merge.

8.4.8 Priority Access Lanes

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 motorway operational speeds on uphill grades.
- Vehicles occupied by more than one person such as buses, taxis or specified high occupancy vehicles (HOV), e.g. a transit lane to provide priority and incentive for people to share vehicle usage. Motorcycles may also use transit lanes.
- Public transport priority where the entry ramp is part of a bus route.

With appropriate regulatory signing, a priority lane is enforceable under the local road rules.

In the context of managing motorway flow, it is generally better to control all entry flows. Therefore, as a general principle, priority access lanes should not be provided unless there is a strategic need. In addition, if a strategic need does exist, preference is generally given to providing a metered priority access lane or a partially controlled/free-flow bypass lane rather than free-flow access to ensure control of all entry flows.

8.4.9 Motorway-to-motorway Ramps

The performance of a smart motorway 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 motorway's capacity. Therefore, the general principle is to control and regulate all traffic entering a smart motorway.

Generally, metering motorway-to-motorway ramps is essential for the overall management of an urban motorway and can potentially provide a net reduction in journey travel times for motorists by contributing to preventing or reducing flow breakdown. Where ramp metering is provided it would only operate when needed and uninterrupted flow operation would be available at other times. If flow breakdown does occur on the smart motorway this would impact not only the smart motorway but also the traffic from the entering motorway.

When high flows enter a motorway from a connecting motorway, having control of these in-flows through ramp metering enables coordination with other ramp signals along the motorway. The ability to balance queues and wait times between coordinated ramps provides greater overall control of flows along the motorway. A further advantage of metering motorway-to-motorway ramps is that it could assist in the ability to manage traffic during incidents and improve the recovery from flow breakdown after an incident.

As drivers enter motorway-to-motorway ramps from high-speed motorways, it is essential that they are alerted to the possible need to stop at signals on the ramp. Signage must indicate the need to slow down and there must be adequate sight distance to the ramp signals to allow them adequate distance to brake. VSL can also be deployed to lower speeds on the ramp when the signals are in operation and thus ensure motorists approach the signals at safe speeds.

8.5 Speed and Lane Use Management Systems

Lane use management systems (LUMS) allocate and manage the available road space through display of variable speed limits (VSL) and lane control signals (LCS) (Figure 8.7). Speed limits and lane status are varied in response to changing road and traffic conditions as they are detected by the motorway management system and TMC operators.

In the past, speed management and lane use management have often been installed separately, such as in tunnel and bridge environments, or reversible lane systems. The current practice for smart motorways is to provide integrated speed and lane use management that enables full control of traffic flows on the mainline in support of smart motorway objectives.

Figure 8.7: Example of LUMS in operation

Merge right from lane one (left lane) due to upcoming lane closures. Speed limit 100 km/h.

8.5.1 VSL-specific Applications

There are a number of VSL-specific applications that can deliver important safety benefits, as well as help to improve traffic flow. These applications often rely on automated algorithms to detect changing conditions and activate a response. They are generally integrated with other speed and lane use management applications within the LUMS system. However, on some motorway sections they may be installed as a stand-alone VSL system.

Speed management can improve road safety by:

- reducing the speed differential between vehicles (i.e. more homogeneous flows)
- minimising lane changing and braking caused by speed differentials
- increasing the time for drivers to react to changing conditions
- reducing the likelihood of an impact, and reducing the crash severity if an impact does occur.

The theory underlining VSL is further explained in Part 2 of the Guide to Traffic Management (Austroads 2015a). VSL applications for safety and flow enhancement are discussed further below.

VSL for queue protection and congestion management

When flow breakdown and shockwaves occur as a result of high demand or an incident, VSL can assist in suppressing shockwaves and can also contribute to increased safety by:

- matching the speed limit to the congested traffic speed
- protecting the back of the queue by slowing vehicles approaching the congestion (thereby reducing the risk of secondary incidents).

VSL for inclement weather conditions

Severe weather conditions, such as heavy precipitation, high winds and ice/snow can have significant impacts on road safety and congestion. Driver behavioural changes during inclement weather can lead to speed differentials that increase the risk of crashes, particularly secondary crashes. For example, extra-cautious drivers will slow dramatically whereas others will make no change which increases the risk of drivers losing control of their vehicle.

Providing a speed limit during inclement weather means a safe speed is set for all drivers, and therefore the speed differential should be decreased. A slower speed also allows more time for drivers to respond if they encounter a hazard (such as water over the road) and reduces stopping distances.

Variable speed limits may be used to improve safety in inclement weather when:

- visibility is reduced by rain, fog or smoke
- pavement conditions are less than desirable (i.e. low coefficient of friction as a result of heavy precipitation, snow or ice, or the road is flooded or has a high probability of flooding)
- weather conditions cause drivers to behave differently (e.g. alter speed) due to different perceptions of risk
- high winds increase the risk of instability (especially for lightly loaded heavy vehicles).

Environmental monitoring systems can be installed on motorways to measure weather and road conditions, and provide an alert to the operator (or an automatic system response), when a configurable threshold has been met. Actions may be to reduce speed limits, as well as other mitigation measures, such as display of warning messages on VMS and activation of water pumps.

Examples of existing weather-based VSL systems on motorways include:

- M1 Pacific Motorway (Mount White), NSW – to reduce speed through tight geometric sections during wet weather.
- Great Western Highway (Meadow Flat to Yetholme), NSW – to reduce speed when there is black ice formation.
- Gateway Bridge, Queensland – to reduce speed during high winds (over 50 km/h).
- M1 West Gate Bridge, Victoria – to reduce speed when there are high winds.
- Tasman Highway (including Tasman Bridge), Tasmania – to reduce speed in response to ice, water on the road or high winds on the bridge, as well as other incidents and congestion events.
- Southern Expressway, South Australia – to reduce speed on a downhill section in response to an incident, maintenance work or inclement weather conditions.
- South Eastern Freeway, South Australia – to reduce speed in response to thick fog.

VSL for flow control

VSL algorithms exist that can activate when at high traffic flows as they get close to a critical level (but before flow breakdown), in order to smooth and stabilise traffic flows through a critical bottleneck and minimise congestion.

The research to date (Papageorgiou, Kosmatopoulos & Papamichail 2008) determines that:

- When VSL is activated at under-critical densities, it can have an adverse impact on traffic efficiency (i.e. leads to increased travel times).
- When activated at critical and over-critical densities, VSL can help to delay the onset of flow breakdown (by shifting the critical occupancy to higher values), but generally has limited ability to prevent flow breakdown.
- VSL at critical levels of operation provides a reduction in the speed differentiation of vehicles (e.g. homogenisation of speeds), which can result in improved flow stability.

Academic research has been undertaken to investigate the integration of VSL with CRS to help meter the mainline upstream of a bottleneck, based on density and occupancy data. The research suggests that the integration of ramp signalling and VSL operations can produce the best benefits (Abdel-Aty et al. 2009).

Emissions and fuel consumption

VSL systems can also be used to reduce speed limits for environmental benefits, i.e. to reduce vehicle emissions and fuel consumption, improve air quality and reduce noise levels. Such systems have been used internationally, such as in Europe, to keep road environmental conditions within regulated levels.

8.5.2 LUMS Applications

LUMS signs are traffic control devices with a regulatory function. These include:

- lane open and speed limit
- merge left, right or both
- lane closed
- exit lanes
- designated turning lane.

Refer to Austroads (2019d) for details. Additional symbols may be used to indicate the use of a lane by a priority vehicle type, such as buses, high occupancy (T2/T3 vehicles) or trucks. Any other symbols used should be supported by the jurisdictional version of the Australian Road Rules.

There are a number of different LUMS applications that contribute to smart motorway benefits. LUMS applications enable reactive management of traffic in response to an incident, event, inclement weather and other causes of non-recurrent congestion. LUMS is also used to provide capacity improvement by enabling operational strategies involving use of the emergency lane for traffic.

LUMS for incident and event management

Once an incident is verified, LUMS can be used to quickly and safely activate traffic management devices (LUMS signs) that will close one or more lanes and manage traffic speed on approach to and through the incident site.

The reduced speed limit improves safety for lane-changing manoeuvres and provides safer conditions at the incident site for the benefit of workers, incident victims and the travelling public. Lane control can be used to improve emergency access to the incident site, as well as to divert traffic off the motorway via an exit ramp in the case of a full carriageway closure or major incident/event.

Lane control and speed limit reductions may also be triggered by planned road works/maintenance activities or other events.

LUMS for capacity increase (i.e. emergency lane use)

LUMS is a critical component of any operational strategy that allows full or part-time use of the emergency lane in order to increase motorway capacity. In the absence of an emergency lane, LUMS is required to provide operators with a means to quickly and safely close lanes to protect an incident site if a crash occurs, and to enable emergency access. Further details on operational strategies involving the absence of an emergency lane or use of the emergency lane as a running lane is provided in Section 8.6.

8.5.3 Types of Control

LUMS is typically operated through a combination of automatic control (i.e. through use of algorithms) and manual control (i.e. by TMC operators). The level of automated compared to manual control may depend on the LUMS application.

LUMS requests (actions) can be generated by multiple triggers, including:

- *Manual requests (by the operator)* – TMC operators may identify the need for activation or changes to LUMS as a result of automatic alarms or alerts from the system (i.e. algorithmic detection without an automated response) or other sources of information on network conditions, such as CCTV monitoring and feedback from road users and operational partners (i.e. the police, public transport drivers etc.).
- *Automatic (algorithmic) requests* – automated VSL algorithms should activate and deactivate when pre-defined thresholds are met. The system should be configurable to change the influence of different algorithms by time-of-day and depending on current traffic conditions. Adjustable controls should also be in place to prevent activation/deactivation when desired.

  Automated systems should still provide (optional) pop-up notifications to TMC operators to inform them of any action that has been taken.

- *Pre-defined response plans* – pre-defined response plans are developed offline and saved so that they can be activated when needed. For example, if required to address a specific combination of one or more lane closures at a particular location. Plans can be time-based or manually activated. Plans may include LUMS responses for changing the priority use of a lane or opening a part-time lane traffic (whether on a fixed-time schedule or in response to a situation).
- *Semi-automatic requests* – the system should also provide the following optional modes to support operations, especially at the early stages of introducing a new functionality or operator training:
  - information-only mode – this mode provides information to operators on what action the system would take when an event is detected. However, it does not implement a response
  - operator-assist mode – this semi-automated mode requires LUMS responses to be manually approved or modified by an operator prior to implementation, which reduces the risk when configuring new algorithms for motorway sections. Once the rate of detection and correct response is high enough, with an appropriately low false alarm rate, the algorithm may be switched to a fully automatic mode.

8.5.4 LUMS Fundamental and Policy Rules

During an incident, the control system automates traffic management according to traffic management practices and operating principles which are classified as fundamental rules (not to be broken) and policy rules (may be changed by the operator).

There are also system rules (automatic rules) that speed up the implementation for LUMS plans. For example, the system may require that any non-default speed showing on a LUMS is accompanied by a flashing annulus. These rules reduce the work required by an operator.

These rules and principles should generally be consistent with traffic engineering and work-site practices and guidelines, including AS 1742.3 (Traffic Control Devices for Works on Roads), road rules and worksite safety codes of practice for traffic management. If LUMS is integrated with other control systems, the fundamental and policy rules should be updated to ensure there is no conflict of rules between each system.

Fundamental rules

Fundamental rules are coded into the control system to provide interlocks that will prevent the display of particular combinations of symbols on adjacent signs over a single carriageway. These interlocks prevent the display of symbol combinations that are hazardous, logically conflicting or ambiguous.

Policy rules

Operational policy rules (also referred to as recommendation rules) are incorporated in the system to support development of traffic management plans when an incident or other event occurs at a specific location on the network. The policy rules enable an automated response to the incident or event that can be quickly implemented by the operator.

The operational policy rules generally replace requirements for a significant number of pre-determined traffic management plans for various scenarios. In some complex traffic arrangements or major emergencies, some adjustments to the plans may be needed.

Policy rules may vary between states. An operator should be warned if a requested LUMS response contradicts a policy rule. The operator may then either modify the response plan to comply with these rules, or bypass the warning and proceed to implement. All policy rules are logged by the system.

8.6 Use of Emergency Lane in Smart Motorway

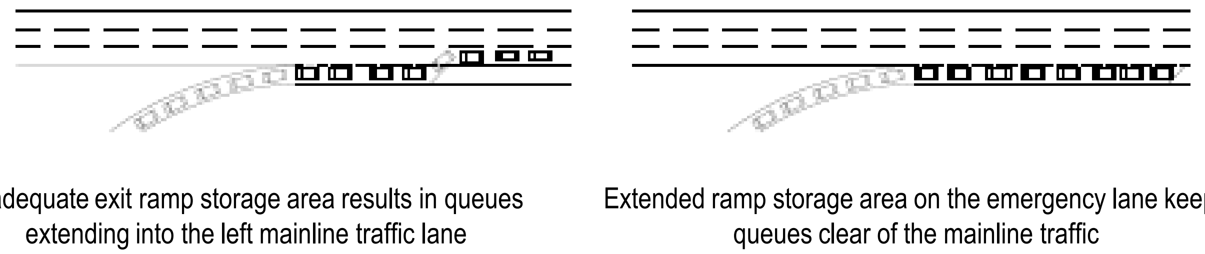
Road safety rules generally prohibit trafficking of the emergency lane (or motorway shoulder) unless related to an incident (i.e. crash or breakdown) or if controlled by signs and line markings on the route. The rules enable restriction of vehicles from using the emergency lane when it is not intended to be open to traffic and allow for exceptions where it is desired to open the shoulder to specific classes of vehicle.

Additional road capacity may be provided on a motorway without the need to undertake extensive and expensive widening treatments by allowing general traffic to use the emergency lane. Alternatively, a new build could be without an emergency lane to increase the number of lanes that can be constructed within the available road corridor. These strategies support the smart motorway objectives to make better use of existing infrastructure whilst maximising motorway capacity, productivity and efficiency (throughput).

There are a number of different applications for use of the emergency lane, including:

- for general traffic (i.e. all vehicle types) on isolated sections in between interchanges to address localised congestion issues
- for general traffic on extended lengths, including through interchanges, to balance capacity along a route
- for queue storage at exit ramps (Figure 8.8), if required to prevent queueing vehicles overflowing onto the mainline and creating safety issues
- for specific vehicles (e.g. taxis and buses), to reduce travel delay for priority vehicles during congested periods.

Figure 8.8: Extension of exit ramp storage using the emergency lane



Source: Adapted from Booz Allen Hamilton (2003), cited in VicRoads (2013a).

Depending on the traffic characteristics and spread of traffic volumes (demand) across the day, the emergency lane may operate as a traffic lane on a part-time basis during peak periods or a full-time basis (commonly referred to as all lane running). Generally, the emergency lane located on the left-hand side of the carriageway is used.

Long bridges and tunnels commonly have no emergency lane due to physical constraints and the higher cost of provision.

The absence of an emergency lane on a part-time or permanent basis may require various measures to be incorporated to project design to manage road safety, particularly during incidents. For example, geometric upgrades, including provision of emergency stopping bays, as well as installation of various traffic management devices to control mainline traffic flows such as LUMS (including VSL).

When the emergency lane is being trafficked, or on an all-lane-running (ALR) section, and there is an incident, then the affected lanes and/or the emergency lane may need to be closed to enable emergency access and to protect the incident victims and responders.

8.7 Motorway-to-arterial Interfaces

This section discusses the issues, principles and strategies for improving operations at arterial/smart motorway interfaces. Refer to Austroads (2016b and 2014b) for details on treatments options.

8.7.1 Management of Entry Ramp Interfaces

The most problematic issue at arterial/entry ramp sites is queue overspill from the ramp onto the arterial road which impedes traffic moving along the arterial road. The implementation of ramp metering as part of a smart motorway system can result in some metered ramps experiencing traffic demands well in excess of their available storage. For these ramps, queue overspill onto the connecting arterial roads can have major ramifications for the arterial network.

Coordinated ramp metering can assist in mitigating the problem of queue overspill by making the metering of ramps upstream and downstream of the problem ramp more restrictive, thereby allowing less restrictive metering on the over-burdened ramp. However, coordinated ramp metering can only go so far to alleviate the problem. Consequently, where traffic demands on a metered ramp exceed its available storage, the metering rate on that ramp may need to be increased above a desirable maximum to alleviate the queue and minimise the impedance on the arterial road. However, the increased rate of vehicle discharge from the entry ramp onto the mainline can severely compromise the performance of the motorway

Alternative treatments will involve adjusting upstream arterial traffic operation to serve as additional storage for motorway-bound vehicles. Supporting treatments involve providing motorists with delay information to allow them to find alternative routes. If operational treatments are still inadequate minor civil works would be required to increase storage.

8.7.2 Management of Exit Ramp Interfaces

The most problematic issue at exit ramp/arterial road sites is long queues forming on the exit ramp when there is inadequate green time provided at the adjoining arterial intersection to allow these vehicles to exit the ramp. Aside from causing long delays for these exiting vehicles, when exit ramp queues build up such that they overspill onto the motorway, they block the left lane of the motorway to traffic progressing beyond the exit ramp.

Even before queue overspill occurs, long queues on an exit ramp have the effect of reducing the available stopping distance on the ramp, meaning exiting vehicles must begin to reduce their speeds on approaching the exit ramp in the left lane of the mainline. This slowing down of exiting vehicles in the left lane impedes other vehicles in this lane travelling beyond the exit ramp and increases the likelihood of rear-end crashes.

On approaching the ramp, many vehicles move into the left lane to exit the motorway. At the same time, other vehicles travelling beyond the exit ramp move out of the left lane to avoid slowing down, further disrupting traffic flow which increases flow turbulence and the risk of a crash on the motorway.

A variety of treatment can be applied which involve increasing the queue storage capacity of the off-ramp, such as use of the emergency lane. Other approaches would involve increasing the discharge capacity of the exit ramp, either through minor civil works or through adjusting the traffic signals to prioritise exit ramp movements.

8.7.3 Management of End-of-motorway Interfaces

For motorways terminating onto arterial roads, control strategies usually only mitigate the resultant congestion. This is particularly so for radial motorways which feed into inner urban areas such that their end is the primary exit for traffic entering the central business district. These motorways will inevitably have large exit flows moving into an already congested inner urban arterial network.

As a general rule, motorways servicing inner urban regions should not be designed to terminate within the central business districts but rather pass through them, providing multiple exit ramps along the way. Ideally, they should begin and end in outer urban or rural regions, on opposing sides of a city so that they can serve as major cross-city traffic corridors.

To accommodate high traffic inflows from the motorway, the end of the motorway should diverge into two or more arterial roads to quickly disperse traffic through the arterial network. This is particularly important when the transition from motorway to arterial roads includes a drop in the number of lanes. Furthermore, signal phases at end-of-freeway intersections should always favour the exiting motorway movements.

8.7.4 Management of Motorway-to-motorway Interfaces

Motorway-to-motorway (M2M) interface problems are commonly encountered in relation to ramps from an uncontrolled motorway onto a smart motorway being left unmetered. In some cases, the decision not to install ramp signals has been based on a perception that motorists should not have to stop when moving from one motorway to another. This is despite the fact the ramp in question enters the smart motorway within a corridor controlled by coordinated signals on all other entry ramps. At peak periods, an unmetered ramp can introduce large volumes of uncontrolled traffic onto the smart motorway, severely compromising the level of control required to optimise the performance of the motorway.

The consequence of having high volumes of uncontrolled traffic moving from one motorway to another is invariably flow breakdown at merges where demand exceeds capacity. This is essentially the same problem that occurs within the merge areas of a motorway with unmanaged entry ramps from arterial roads, but often the scale of the problem is much greater at M2M ramp merges.

Introducing ramp signals on a motorway-to-motorway ramp which enters a smart motorway can greatly increase the level of control achievable on the smart motorway. When flow breakdown happens on an M2M ramp, vehicles using the ramp are forced to slow down or come to a complete stop. Ramp signals can improve merging so that vehicles queuing on the ramp do not have to come to a complete stop; instead they slowly progress along the ramp in a rolling queue. Progression along the ramp may improve during peak periods when ramp signals are introduced.

9. Performance Indicators

National performance indicators for network operations on arterial roads and freeways have been proposed by Austroads (Austroads 2007e). They are summarised in Table 9.1.

Table 9.1: National performance indicators for network operations for general traffic

Performance measurement area	Performance measure	Comments
Traveller efficiency	Travel speed	This indicator monitors congestion in terms of speeds. It is derived from spot speeds on freeways measured directly using point sensors such as a pair of loops. On arterial roads, it can be derived from the inverse of travel times estimated from an ATC system.
	Variation from posted speed	This indicator monitors the proportions of a road network at various levels of deviation from posted speed limits on freeway or arterial road links.
	Arterial intersection performance	This indicator monitors the proportion of an arterial road network at various levels of unusual or extreme congestion.
	Lane occupancy	This indicator monitors the average number of persons per lane per hour during a specified period on a representative sample of arterial roads and freeways.
	Vehicle occupancy	This indicator monitors the average vehicle occupancy (persons/vehicle) on a representative sample of arterial roads and freeways, and is also an input to the calculation of the lane occupancy measure.
Reliability	Travel speed variability	This indicator measures the variability of speeds by calculating the coefficient of variation. It is displayed as the proportions of a road network at different levels of variability in a measurement time period.
	Speed and flow	This indicator is based on the product of speed and flow. A high productivity is achieved if both speed and flow are maintained near maximum values (i.e. near free-flow speed and capacity flow).

Source: Austroads (2007e).

The formulation of these indicators is such that, while being primarily aimed at reporting the performance of a whole arterial network, the inputs are gathered at a link or segment level and the indicators are therefore candidates for performance measures for the aggregate effect of traffic operations at scales ranging from individual links to whole networks. The national indicators have also been chosen and formulated so that, with the exception of the vehicle-occupancy and lane-occupancy measures, the underlying data can be automatically acquired from traffic control systems. Further detail on their formulation can be found in Part 4 of the Guide to Traffic Management (Austroads 2016a).

The values reported for these performance indicators reflect the aggregate outcomes of a range of traffic operations activities along with the effects of changes to the road infrastructure. The individual contributions of each traffic operations activity will not necessarily be evident in them; separate performance indicators for each major traffic operations function are required for this.

For further reading on performance measures and measurement tools for freeways and arterial roads, refer to Austroads (2007e and 2007h).

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Appendix A Special Events: Transport Management Plan Template

Figure A 1 provides an example of a transport management plan template (Roads and Traffic Authority NSW 2006). It illustrates the planning requirements for the top three classes of special event. It assumes the event classifications described in Table 5.4.

Figure A 1: Special event transport management plan template

Special Event Resources

Special Event Transport Management Plan Template

Refer to Chapter 7 of the Guide for a complete description of the Transport Management Plan

1 EVENT DETAILS

1.1 Event summary

Event Name: ....

Event Location: ....

Event Date: .... Event Start Time: .... Event Finish Time: ....

Event Setup Start Time: .... Event Packdown Finish Time: ....

Event is ☐ off-street ☐ on-street moving ☐ on-street non-moving
☐ held regularly throughout the year (calendar attached)

1.2 Contact names

Event Organiser *..

Phone:.................. Fax:.................. Mobile: .... E-mail: ....

Event Management Company (if applicable)..

Phone:.................. Fax:.................. Mobile: .... E-mail: ....

Police ....

Phone:.................. Fax:.................. Mobile: .... E-mail: ....

Council..

Phone:.................. Fax:.................. Mobile: .... E-mail: ....

Roads & Traffic Authority (if Class 1)..

Phone:.................. Fax:.................. Mobile: .... E-mail: ....

**Note: The Event Organiser is the person or organisation in whose name the Public Liability Insurance is taken out.*

1.3 Brief description of the event (one paragraph)

2 Risk Management - Traffic

CLASS 1 CLASS 2 CLASS 3

2.1 Occupational Health & Safety - Traffic Control

☐ Risk assessment plan (or plans) attached

2.2 Public Liability Insurance

☐ Public liability insurance arranged. Certificate of currency attached.

2.3 Police

☐ Police written approval obtained

2.4 Fire Brigades and Ambulance

☐ Fire brigades notified

☐ Ambulance notified

3 Traffic and Transport Management

CLASS 1 CLASS 2 CLASS 3

3.1 The route or location

☐ Map attached

3.2 Parking

☐ Parking organised - details attached

☐ Parking not required

CLASS 1 CLASS 2

3.3 Construction, traffic calming and traffic generating developments

☐ Plans to minimise impact of construction activities, traffic calming devices or traffic-generating developments attached

☐ There are no construction activities, traffic calming devices or traffic-generating developments at the location/route or on the detour routes

3.4 Trusts, authorities or Government enterprises

☐ This event uses a facility managed by a trust, authority or enterprise; written approval attached

☐ This event does not use a facility managed by a trust, authority or enterprise

3.5 Impact on/of Public transport

☐ Public transport plans created - details attached

☐ Public transport not impacted or will not impact event

3.6 Reopening roads after moving events

☐ This is a moving event - details attached.

☐ This is a non-moving event.

3.7 Traffic management requirements unique to this event

☐ Description of unique traffic management requirements attached

☐ There are no unique traffic requirements for this event

3.8 Contingency plans

☐ Contingency plans attached

Class 1 | Class 2

3.9 Heavy vehicle impacts

☐ Impacts heavy vehicles - RTA to manage

☐ Does not impact heavy vehicles

3.10 Special event clearways

☐ Special event clearways required - RTA to arrange

☐ Special event clearways not required

4 MINIMISING IMPACT ON NON-EVENT COMMUNITY & EMERGENCY SERVICES

CLASS 1 | CLASS 2 | CLASS 3

4.1 Access for local residents, businesses, hospitals and emergency vehicles

☐ Plans to minimise impact on non-event community attached

☐ This event does not impact the non-event community either on the main route (or location) or detour routes

4.2 Advertise traffic management arrangements

☐ Road closures or restrictions - advertising medium and copy of proposed advertisements attached

☐ No road closures or restrictions but special event clearways in place - advertising medium and copy of proposed advertisements attached

☐ No road closures, restrictions or special event clearways - advertising not required

4.3 Special event warning signs

☐ Special event information signs are described in the Traffic Control Plan/s

☐ This event does not require special event warning signs

4.4 Permanent Variable Message Signs

☐ Messages, locations and times attached

☐ This event does not use permanent Variable Message Signs

4.5 Portable Variable Message Signs

☐ The proposed messages and locations for portable VMS are attached

☐ This event does not use portable VMS

6 APPROVAL

TMP Approved by: .... Event Organiser .... Date

7 AUTHORISATION TO *REGULATE TRAFFIC

Council's traffic management requirements have been met. Regulation of traffic is therefore authorised for all non-classified roads described in the risk management plans attached to this TMP.

Regulation of traffic authorised by: .... Council .... Date

The RTA's traffic management requirements have been met. Regulation of traffic is therefore authorised for all classified roads described in the risk management plans attached to this TMP.

Regulation of traffic authorised by: .... RTA .... Date

* *"Regulate traffic" means restrict or prohibit the passage along a road of persons, vehicles or animals* (Roads Act, 1993). *Council and RTA require traffic to be regulated as described in the risk management plans with the layouts installed under the direction of a qualified person.*

Source: Roads and Traffic Authority NSW (2006).

Appendix B FHWA Major Event Planning Checklists

The following tables are derived from the US Federal Highway Administration (FHWA) manual Managing Travel for Planned Special Events (Latoski et al. 2003). While they are oriented to a major event at a single location, and do not address the needs of moving events such as parades, cycle races or marathons, they provide a useful list of issues to be addressed which can be supplemented as necessary to suit other needs.

Table B 1: Contingency plan checklist

Contingency
Weather • severe weather outbreak • flooding on event site access routes • flooding in event parking areas • parking during wet weather.
Security threat
Major traffic incident
Delayed event
Event cancellation
Absence of trained personnel and volunteers on the day of event
Equipment breakdown
Demonstration or protest
Unruly spectator behaviour
Overcrowding
Event patron violence

Source: Latoski et al. (2003).

Table B 2: Site and parking plan checklist

Element	Provision
Event patron parking areas	Highlight free, pay (rates), and reserved (permit) parking areas. Indicate lots where tail-gating is permitted.
	Show specific parking area access points and state restrictions.
	Indicate number of entrance/exit lanes (or servers) at each access point.
	Designate lots by a number or letter and provide lot-specific directions.
	State time parking areas open, particularly if time varies by parking area.
	Discuss features of each parking area (e.g. paved, staffed, lighting, security).
	State estimated walking time from each parking area.
	Indicate connecting pedestrian access routes.
	Show overflow parking areas, state distance from venue, and indicate criteria for operation (e.g. sell-out).
	Indicate parking areas for motorcycles.
	Indicate parking areas for recreational vehicles (e.g. overnight parking).
	Furnish map of available off-site parking areas: • include information on street regulations (e.g. one- or two-way) and connections to freeways and major arterials • state on-street parking restrictions • specify private parking area regulations (e.g. egress control) • indicate location of entrance/exit points to off-street parking areas • include rates if available • show restricted off-site parking areas (e.g. residential neighbourhoods, etc.).

Element	Provision
Gate access information	Indicate gate names as shown on event patron tickets.
VIP information	Show VIP (e.g. official guest/sponsor) parking areas.
	Show credential pick-up location.
	Show hospitality areas.
Shuttle bus route and stations	Display shuttle route and all stations. State cost, and emphasise free services.
Drop-off/pick-up sites	Show access points and circulation lanes for transit/taxi/limo/shuttle service. Show exclusive bus lanes.
	Show transit/express bus stations.
	Indicate general drop-off/pick-up sites where turnaround is permitted.
	Indicate valet parking drop-off.
	Show disabled drop-off/pick-up site.
Other parking areas	Show express/charter bus parking area.
	Show limousine parking area.
	Show media parking area.
	Show venue employee parking area.
Disabled parking areas	State specific location (e.g. first row) of disabled-only spaces in general parking areas.
	Indicate number of spaces available.
Other considerations	Show aerial map. Promote advance purchase (permit) options.
	Indicate towed vehicle (e.g. illegally parked) pick-up area.
	Emphasise new provisions (e.g. new parking areas, etc.).
	Present map in grid format for easy reference.
	Prepare maps for different venue events if parking plan varies.
	Draw map to scale.
	Show private property.
	Display landmarks.
	Indicate municipal fireworks viewing areas.

Source: Latoski et al. (2003).

Table B 3: Pedestrian access plan checklist

Element
Show recommended pedestrian access routes.
Show pedestrian bridges and tunnels.
Indicate special pedestrian crossing tactics (e.g. street closure or mid-block crossings).
Show shuttle bus route, direction of travel, stop locations, and loading and unloading areas.
Show vertical connections between infra-structure levels (e.g. stairs, escalator, elevator, ramps).
Show designated pedestrian crossings at street use event venues.
Indicate special regulations.
Highlight pedestrian access routes and crossings suitable for disabled event patrons.

Source: Latoski et al. (2003).

Table B 4: Traffic flow plan checklist

Element	Provision
Event patron corridor flow route	Indicate recommended freeway ramps, by route direction, to/from event venue or specific parking area. Indicate corridor target points representing a connection to local flow routes. State freeway or arterial lane assignments for event traffic (e.g. event traffic two right-lanes). Furnish information on roadway construction projects, as applicable, and indicate alternate routes. Indicate modified ramp control tactics (e.g. closures/additional lanes). Show freeway interchange configurations (and direction of travel) and exit numbers. State tolls, if applicable.
Event patron local flow route	Show connection to corridor flow route. Indicate local streets that connect to freeway entrance/exit ramps. Indicate recommended flow route to/from general and reserved parking areas (minimum) or individual parking areas (recommended). Indicate one-way streets. Show all road segment closures. Specify permitted turning movements. Emphasise controlled turn areas (turns prohibited or only one turn allowed). List modified roadway striping (e.g. reversible lanes or contra-flow). Indicate event participant/VIP access routes.
Traveller information	Promote use of regional park & ride locations and event satellite parking areas. Indicate commercial radio and highway advisory radio frequencies with event travel information. Stress importance of following route and adhering to traffic control officer instructions.
Traffic management team information	Include contingency maps detailing routes to overflow parking areas. Provide written directions for diverting corridor flow routes via local street system. Indicate alternate routes for ingress and egress to same target point.
Other travel modes/user groups	Show transit routes and state corresponding route number(s). Show preferred taxi routes. Indicate bicycle routes. Indicate pedestrian routes.
Other considerations	Provide information on both ingress and egress flow routes. Emphasise law enforcement endorsement of recommended routes and directions. State travel times (by mode of travel) and distances (e.g. from select origins). State when special traffic flow routes go into effect and terminate. Disseminate written ingress/egress driving directions. Indicate potential points of confusion along recommended route (e.g. freeway exits, turning movements). Indicate heavy vehicle restrictions. Indicate expected congested/non-congested areas. Use callouts to highlight critical movements. Label all streets and freeways. Colour-code recommended routes to specific parking areas. Emphasise new provisions (e.g. new road closures or route). Prepare maps for different venue events if parking plan varies. Show parking areas. Show venue gates. Draw map to scale. Show private property. Display landmarks.

Source: Latoski et al. (2003).

Table B 5: Traffic control plan checklist

Element	Provision
Freeway control plan	Specify maintenance and protection of traffic per MUTCD guidelines (e.g. location of traffic control equipment, equipment quantities, and safety signs).
	Indicate ramp control and capacity modifications.
	Highlight exclusive traffic flows (e.g. unimpeded merge, etc.).
	Dimension weaving area, acceleration/deceleration lane lengths, ramp length.
	Indicate potential bottleneck locations for surveillance monitoring.
Street control plan	Show closed road segments.
	Indicate directional lane control (e.g. alternative lane operations).
	Show one-way streets.
	Indicate number of ingress and egress lanes at each venue access point (e.g. parking areas, pick-up/drop-off points).
	Show street use event route.
	Indicate parking restrictions.
	Indicate location of command post(s).
	Integrate with signing plan (e.g. show route trailblazer signs).
Intersection control plan	Specify maintenance and protection of traffic per MUTCD guidelines (e.g. location of traffic control equipment, equipment quantities, and safety signs).
	Show permitted pedestrian movements and crosswalk locations.
	Indicate approach lane designations and pavement markings.
	Indicate traffic control.
	Highlight exclusive/permitted traffic flows (indicate approach lane and corresponding receiving lane).
	State special regulations (e.g. turn prohibition, exclusive bus lane, resident/permit only movement).
	Show approach closures.
	Indicate parking restrictions.
	Indicate location of traffic control officers.
	Indicate location of equipment storage area at intersection.
Signing plan	Show location of permanent/portable changeable message signs.
	Show location of permanent/portable highway advisory radio stations.
	Indicate CMS/HAR message sets • default ingress and egress • contingency scenarios.
	Show location of temporary static signs and message.
	Indicate location of dynamic blank-out signs.
Equipment location plan	State number of traffic cones, drums, and barricades required at designated locations. Indicate equipment staging areas (e.g. shoulder, median, intersection corner).
	Indicate location of equipment storage areas.
Other considerations	Provide plans for both ingress and egress operation.
	Indicate roadway construction zones.
	Include table of quantities.
	Show aerial map.
	Draw map to scale.
	Display landmarks.

Source: Latoski et al. (2003).

Appendix C Special Event Planning Checklist

Table C 1 lists the key issues considered in planning for the Hamilton 400 V8 street race in New Zealand. A major event such as this, involving the closure of a number of roads and isolation of activities within the circuit, clearly involves a large range of issues. The items considered under each issue heading are listed.

Table C 1: Hamilton 400 V8 street race issues and considerations

Key issues	Considerations
Understanding of the key characteristics of the local environment	Transportation opportunity for all modes. Network and facility constraints. Weather and surface types if parking on grass. Public works programs. Other event planning – develop a calendar of events. Communications network capability limitations/opportunities. Weekday/weekend/school holiday variations. Local road network safety issues, high risk areas.
Event needs and constraints	Road closures. Set up and breakdown of infrastructure. Security. Dangerous goods storage. Public infrastructure accessibility. Bulk storage areas/facilities. One-off or ongoing (recurring).
Transportation event planning	Transportation working party comprising transport advisers, road agency representatives, planning consent advisor, police, fire, ambulance, passenger transport representative Event management planning for: • event set up and breakdown • traffic operations • passenger transport (bus, coach, rail, taxi, ferry) • walking and cycling • parking • evacuation and emergency services • business continuation • communications.
Transportation movement assessment	Attendance forecasts. Origin/distribution. Accommodation availability. Arrival/departure profiles. Consenting requirements (resource and building consents). Cross boundary issues of jurisdiction and effect. Mode split. Sensitivity to variation in demand levels. Network capability/level of service. Modelling (network/local). Corridor and locality management effects, mitigation. Temporary or permanent management measures.

Key issues	Considerations
Parking	Satellite/distributed/local. On-street versus off-street. Free versus pay. Lot access/egress capacity. Hard surface versus paddock. Contingency for wet weather. What if vehicles get stuck. Event cordon management in commercial/residential areas. Time limits/restriction/prevention. Commercial/residential street access protection (i.e. by permit). Drop-off and pick-up and park and ride connections.
Passenger transport	Event coach drop-off and parking. Regional/district passenger transport promotion opportunity. Public/private funding partnerships. Capacity on existing network services. Re-routing current services. Free or fixed fee city-wide bus transport. Peak loading/unloading demands. Public/private rail initiatives. Taxi and ferry (harbour and/or river) services. Terminal capacity, existing terminal or temporary (on or off-street). Drop-off and pick-up and cross mode connections.
Walking, cycling and disabled access	Peak demands. Bridge width and stair capacity limitations. Event access and ticketing queuing. Dedicated routes. One-way versus two-way movement. Cycle parking including security locking and surveillance e.g. cables staked to the ground. Stairs versus ramps. Pathway surface risk areas, fix trip hazards.
Temporary traffic management	Corridor management, roadside parking controls. Breakdown and incident response teams at congestion points. Use of shoulders for additional lanes. Network flow balancing across strategic arterials. Temporary turn restrictions or 'sandbag' roundabouts. Double right turns with warden control. Stopping one leg at crossroad signals to enable three phase signals and increased main flow green time. SCATS event timing settings at signals. Variable message signing. Clearway signing. CCTV surveillance from communications centre. Deputised traffic wardens. Priority flow changes at intersections i.e. using lane controls or priority to roundabout. Tidal flow on central medians. Residential area access (entry) control i.e. by permit only. Enforcement support.
Permanent traffic management	Integrate with planned public works i.e. additional lanes, increased storage, tidal flow capability, temporary dual-laning options. New construction to mitigate event effects.

Key issues	Considerations
Control centre establishment	CCTV surveillance for traffic flow and crowd control. Staff with emergency services, parking control, event manager/organiser/promoter. Wired and wireless (radio telephone) communications. Communications and public announcements co-ordination.
Other considerations	Program the main event to avoid critical traffic periods. Develop a shoulder event program to disperse peak arrival/departure flows, such as music, entertainment, merchandising. Distribute access and parking information packages with ticket sales. These can be tailored according to trip origin and destination. Advertise key access route using radio, newspaper, television. Establish an information website (possibly co-hosted page with the local authority) containing key event and traffic management information. Develop monitoring and reporting loop for continual improvement for ongoing/recurring events.

Source: Traffic Design Group (2007).

Appendix D Road Occupancy Applications

The following examples of road occupancy licence applications from the Transport NSW Transport Management Centre illustrate the matters requiring consideration in ensuring the maintenance of an acceptable level of service and road user safety when roadworks, utility works in the road and other activities having a similar impact on traffic are undertaken.

Two examples are given. Figure D 2 relates to road development including road construction, road maintenance, traffic signal construction or maintenance and utility works that involve road openings. The common element is that the activities involve the road infrastructure and therefore may require consideration by the asset manager for the infrastructure.

Figure D 2 relates to non-development activities such as:

- occupation of a traffic lane to support building construction activities
- mobile crane operation from the roadway
- public utility infrastructure maintenance.

It is provided to illustrate the range of activities that can be regarded as road occupancies requiring pro-active management to maintain traffic level of service.

Figure D 3 is a checklist required in support of either type of application, and forms the basis for consideration of the traffic impacts of the activity.

Figure D 2: Road occupancy licence application (development)

FORM D

Road Occupancy Licence Application

Development Activities

NSW | Transport Management Centre

Is this an extension of existing / previous licence? ☐ No ☐ Yes - Licence #. ____________ (original attached)

Was this application entered on-line? ☐ No ☐ Yes - Application #. ____________ (on-line print out attached)

CONTACTS	Proponent Organisation		Your Reference No.	
	Proponent Contact Name		On-site Company	
	Phone		On-Site Contact Name	
	Fax		On-site Phone	Fax:
	Email			
LOCATION	Subject Road		UBD Reference	
	From (Cross Street)		To (Cross Street)	
	Suburb		Council	
TIMES	Requested Start & End Dates	Enter start date of 1st shift & start date of last shift	Estimated Duration of Activities	Duration for this application ONLY, in number of hours/shifts
	Requested Times	For example Mon - Fri 1000 - 1500 , Sat 0700 - 1300		

PROPOSED ACTIVITIES	Project			
	Work Description for this Application			Current Speed Limit: Km/h
	Licence Type	☐ Intersections ☐ New Construction ☐ Road Opening	☐ Repair ☐ Road Widening ☐ Signs/Signals	☐ Traffic Repairs ☐ Resurfacing ☐ Line Marking
	Lane/s or Shoulder/s Closed	☐ Median Shoulder ☐ Shoulder ☐ Lane 1 (kerb Lane/s)	☐ Lane 2 (next after kerb lane) ☐ Lane 3 ☐ Lane 4	Total no. of lanes to be closed at any one time? *(in same direction)*: ______ lane(s) of ______
	Direction	☐ All directions	☐ East bound ☐ West bound ☐ East and West bound	☐ North bound ☐ South bound ☐ North and South bound
	Flow Management	☐ Standard lane merge ☐ Contra Flow ☐ Stop / Slow Control	☐ Detour (other roads) ☐ Detour (side-track) ☐ Portable Signals	☐ Mobile works ☐ Short term / Intermittent works ☐ Non-Trafficable Area
	Miscellaneous	Turning Bay/s affected? ☐ Yes ☐ No	Speed reduction? ☐ Yes *(Apply for SZA)* ☐ No	Community Notification ☐ Newspaper ☐ VMS ☐ Letterbox drop
	Note: If the application proposes changes to the road asset itself, a Road Development Licence is required from the RMS Asset Management Branch before a road occupancy licence can be assessed. Refer to Road Occupancy Manual for details.		Quote RMS Asset Maintenance Reference Number:	
RMS	If this project is managed by the RMS, fill in the following:			
	RMS Branch: ____________		RMS Contact: ____________	
SIGN	I hereby apply for a Road Occupancy Licence:		**Please allow a minimum of 10 working days to process this application.**	
	Signature: ____________		Date: ____________	

- Fax to the RMS office relevant to the location of the application.
- Refer to Explanatory Notes for fax numbers.

TMC - SOP - 502016 - F1

Catalogue No. 45062798, Form No. 835 (11/2011)

Source: Roads and Maritime (2011).

Figure D 3: Road occupancy licence application (non-development)

FORM **N**

Road Occupancy Licence Application

Non-Development & Special Event Activities

NSW | Transport Management Centre

Is this an extension of existing / previous licence? ☐ No ☐ Yes - Licence #. ____________ (original attached)

Was this application entered on-line? ☐ No ☐ Yes - Application #. ____________ (on-line print out attached)

CONTACTS	Proponent Organisation		Your Reference No.	
	Proponent Contact Name		On-site Company	
	Phone		On-Site Contact Name	
	Fax		On-site Phone	Fax:
	Email			
LOCATION	Subject Road		UBD Reference	
	From (Cross Street)		To (Cross Street)	
	Suburb		Council	
TIMES	Requested Start & End Dates	Enter start date of 1st shift & start date of last shift	Estimated Duration of Activities	Duration for this application ONLY, in number of hours/shifts
	Requested Times	For example Mon - Fri 1000 - 1500 , Sat 0700 - 1300		
PROPOSED ACTIVITIES	Project			
	Work Description for this Application		Current Speed Limit: Km/h	
	Licence Type	☐ Abnormal Load Movement ☐ Bridge ☐ Building Construction ☐ Building Work Zone ☐ Special Event	☐ Hoardings ☐ Hazard Reduction ☐ Utility Maintenance ☐ SRA Works ☐ Other: ________	☐ Investigation ☐ Landscaping / mowing ☐ Police Operations ☐ Crane ☐ Site access
	Lane/s or Shoulder/s Closed	☐ Median Shoulder ☐ Shoulder ☐ Lane 1 (kerb Lane/s)	☐ Lane 2 (next after kerb lane) ☐ Lane 3 ☐ Lane 4	Total no. of lanes to be closed at any one time? *(in same direction)*: ______ lane(s) of ______
	Direction	☐ All directions	☐ East bound ☐ West bound ☐ East and West bound	☐ North bound ☐ South bound ☐ North and South bound
	Flow Management	☐ Standard lane merge ☐ Contra Flow ☐ Stop / Slow Control	☐ Detour (other roads) ☐ Detour (side-track) ☐ Portable Signals	☐ Mobile works ☐ Short term / Intermittent works ☐ Non-Trafficable Area
	Miscellaneous	Turning Bay/s affected? ☐ Yes ☐ No	Speed reduction? ☐ Yes ______ km/h *(Apply for SZA)* ☐ No	Community Notification ☐ Newspaper ☐ VMS ☐ Letterbox drop
RMS	If this project is managed by the RMS, fill in the following:			
	RMS Branch:		RMS Contact:	
SIGN	I hereby apply for a Road Occupancy Licence:		Please allow a minmum of 10 working days to process this application.	
	Signature: ____________		Date: ____________	

- Fax to the RMS office relevant to the location of the application.
- Refer to Explanatory Notes for fax numbers.

TMC-SOP-502016 - F2

Catalogue No. 45062797 Form No. 834 (11/2011)

Source: Roads and Maritime (2011).

FORM C

Road Occupancy Licence (ROL) Checklist

NSW Transport Management Centre

(THIS DOCUMENT MUST BE SUBMITTED WITH EACH ROAD OCCUPANCY APPLICATION)

CONTACT	Proponent's Organisation		* Contact Phone	
	*Proponent's Name		* Contact Mobile	
LOCATION	*Subject Road		*Suburb	
	*From (Cross Street)		*To (Cross Street)	

Has a Site inspection been conducted in the past two weeks? Two photographs (one each direction) of site attached. ☐ Yes

Any significant features of the site noted : (Tick below those which are applicable) ☐ Yes ☐ No

- signals within 100m of site ☐
- signal phases effects (lanes & turning lanes) ☐
- roundabouts within 100m of site ☐
- occupancy near a tidal flow ☐
- number of traffic lanes in each direction **(insert number)** ______ ☐
- adjacent significant land use with major egress such as hospitals/schools/supermarkets ☐
- raised median / divided carriageway ☐
- pavement type ☐ Bitumen ☐ Concrete ☐ Other
- any kerbside restrictions such as **(specify appropriate restriction)** ☐
  1. Clearways / bus or transit lanes ☐
  2. Designated Parking Restrictions ☐
  3. Loading Zones ☐
  4. Bus stops ☐
  5. Taxi Ranks ☐

Any evidence of concurrent adjacent roadworks / activities / off-road developments ☐ Yes ☐ No

IF YES PLEASE SPECIFY: ____________________

Relevant traffic volume data obtained (Traffic Volume Data Book) ☐ Yes ☐ No

- Days/times of lowest traffic volumes noted
- Are times occupancy requested consistent with traffic volumes (above)
- Does your Traffic Management Plan (TMP) indicate how flow capacity is maintained

Has this Traffic Management Plan been prepared by a person in possession of a current **Select/Modify Traffic Plans** qualification or higher ☐ Yes ☐ No

If YES please supply **Name** & **Licence No**: ____________________

Will your organisation be undertaking or supervising the works described in the application. ☐ Yes ☐ No

Consideration has been given to construction noise and other environmental impacts on residents (where applicable) and the appropriate measures will be taken to minimise these impacts, particularly noise to residents ☐ Yes ☐ No

If YES please supply details: ____________________

Comments ____________________

RMS Asset Management **(02) 8849 2114** notified for Road opening etc:

☐ **No** Reason ____________ ☐ **Yes** If YES please supplied Reference no. ____________

SIGN	Applicant's Name:	Signature: ____________	Date: ____________

*** Denotes mandatory fields that are required to be completed**

TMC-SOP-502016 A3

Catalogue No. 45062800 Form No. 837 (1112010)

Source: Roads and Maritime (2011).

Appendix E Worked Example of Signal Design

E.1 Introduction

This appendix presents a worked example to illustrate various aspects of signalised intersection timing, performance analysis and implementation procedures for a signalised intersection design. A four-way intersection controlled by actuated signals is considered. Under current conditions (Design 1), a two-phase system is used, which is inadequate due to filter right turn movements against heavy opposing through flows. As a result, improvements to the intersection geometry and signal phasing are considered (Design 2).

Signal timing and performance analyses presented in this section were carried out using the SIDRA INTERSECTION software package (Akcelik & Associates 2011). The aim is to ensure that the model replicates the observed conditions for current Design 1, and then to see that the proposed Design 2 provides satisfactory operating performance. The analyses assume actuated signal operation, and signal coordination applies to some movements.

Appendix E.2 contains listings of the input data and output information required for timing and performance analyses of signalised intersections. Appendix E.3 and E.4 describe input data and analysis results for Designs 1 and 2, respectively.

Decisions regarding improvements to intersection design and operational conditions should be made considering a wide range of operating conditions. Therefore, intersection timing and performance analyses should ideally be carried out for several typical flow periods, including am and pm peak periods, business hours, medium off-peak and light off-peak periods. For the purpose of this worked example, conditions during one peak period only will be considered.

E.2 Input and Output Requirements

E.2.1 Input Data

The first step in timing and performance analyses of a signalised intersection is preparation of input data using an intersection layout plan, and signal phasing, design volumes and other information on traffic characteristics at the intersection. The following is a summary of the input data for timing and performance analyses of signalised intersections.

Geometric data

- Intersection configuration (cross-intersection, T-intersection, etc.).
- For each intersection leg:
  - two-way, one-way approach or one-way exit
  - signalised pedestrian crossings and type (one-stage or two-stage)
  - banned movements
  - number of approach and exit lanes (at the stop line)
  - median width at the stop line if a median strip exists
  - approach short lanes (limited queuing space due to turn bays or parking)
  - exit short lanes (merging due to reduced number of exit lanes)
  - bus only, tram only and bicycle lanes

- details of parking arrangements, bus stops, tram stops, emergency access for each approach lane:
  - lane type and control including slip lane (give-way, stop, signalised) and continuous lane
  - lane discipline (left turn, through, right turn, exclusive or shared)
  - lane width
  - grade (negative for downhill, positive for uphill)
  - lane (storage) length
  - free (non-blocking) queue values for shared lanes
  - basic saturation flow
  - saturation speed
  - number of parking manoeuvres and buses stopping (affecting saturation flow)
  - lane utilisation and capacity adjustment.

Volume data

- Demand volume counts (or estimates) in vehicles per 15 minutes, 30 minutes or 60 minutes, in origin-destination format describing left turn, through, right turn as well as any diagonal or U-turn movements for each movement class (light vehicles, heavy vehicles, buses, bicycles, etc.).
- Volume data method (separate movement class values, total volume and percentage values for movement classes, or total volume and movement class values in vehicles).
- Volume factors including peak flow factors for peaking effects, flow scales, vehicle occupancy (persons per vehicle) and growth rates for design life analyses.
- Pedestrian volume counts.

Signal control data

- Signal analysis method, i.e. fixed-time or actuated analysis (if the intersection runs under SCATS control, fixed-time analysis is recommended as more appropriate for green split calculations using the equal degree of saturation principle).
- Signal phase sequences to be tested (one or more).
- Phase data (vehicle and pedestrian movements which operate in each phase, yellow times and all-red times).
- Vehicle movement timing data (vehicle start loss and end gain times, minimum and maximum green times).
- Pedestrian movement timing data (pedestrian start loss and end gain times, minimum green and maximum green times, crossing speed, minimum walk time, minimum clearance time, clearance time overlap).
- Phase green times and cycle time if data observed in the field or reported by SCATS or other control system are available (for testing current traffic conditions under current signal timings).
- Cycle time calculation options (practical cycle time, optimum cycle time, user-given cycle time, user-given phase times).
- Green split priority option for allocation of any excess green times in long cycles when a cycle time is specified.
- Signal coordination data (percentage arriving during green or arrival types describing progression quality).
- Left turn on red where applicable.

Movement operational data

- Approach and exit speeds, approach travel distances.
- Negotiation radius, speed and distance for movements through the intersection.
- Queue space, vehicle length.
- Various parameters for saturation flow adjustment including heavy vehicle, turning vehicle and pedestrian effects.
- Movement priorities (opposed and opposing movements) and gap-acceptance parameters for opposed turns (filter right turn and slip lane left turn movements).
- Practical (target) degrees of saturation for signal timing and spare capacity calculations.

Default values

SIDRA INTERSECTION provides default values for most input data items, representing commonly occurring conditions, and various calibration facilities including sensitivity analysis. The default values can be used where data are not available. The single most important parameter for calibration of signalised intersection capacity and performance modelling is the saturation flow rate (for further guidance refer to Akcelik & Associates 2011 and Austroads 2017c).

Input data auditing

The intersection Layout and Volume Summary displays help to check input data visually. The Input Report lists all input data to help the analyst to check the input data in table form. A separate INPUT COMPARISON program helps to audit input data including identifying where input data have been specified to replace the default values (refer to Akcelik & Associates 2011).

E.2.2 Output Information

Various output statistics for timing and performance analyses of signalised intersections are presented at different aggregation levels, i.e. per movement (vehicle and pedestrian), per lane, per lane group or approach, and for the intersection as a whole. Average, total or maximum values are used as applicable (e.g. average delay, total operating cost, and maximum degree of saturation).

Detailed information about output statistics and analytical models used for estimating them can be found in the SIDRA INTERSECTION User Guide (Akcelik & Associates 2011). Output data as presented in various output reports and displays (Intersection Summary, Lane Summary, Movement Summary, Level of Service Summary, Phasing Summary, Movement Timing, Movement Displays, Graphs and Flow Displays) include the following.

Processed data

Processed data includes arrival (demand) flow rates that are determined by adjustments to user-specified volumes to take account of the volume counting period, peak flow factors, flow scales and growth rates.

Signal timings

- Cycle time, displayed green times for phases and effective green times for movements (for actuated signals and where the fixed-time analysis method is used to emulate SCATS timings, the phase green time, therefore the cycle time, are estimated average values).
- Critical movement analysis results.
- Cycle time or maximum green time optimisation results.
- Progression and actuated signal parameters.
- Estimates of SCATS parameters (maximum flow, occupancy, space time, etc.).

Capacity

- Saturation flow estimates, including indications of any lane under-utilisation and shared lanes that operate effectively as exclusive lanes (de facto exclusive lanes).
- Capacity and degree of saturation.
- Practical spare capacity.

Performance

- Delay, queue length (average and percentile), stop rate, proportion queued, etc.
- Probability of blockage (probability of exceeding the available queue storage space).
- Level of service.
- Average speed including the effect of delay.
- Driver characteristics (driver response time, average queue space, etc.).
- Operating cost, fuel consumption and pollutant emissions (carbon dioxide, carbon monoxide, etc.).

In the worked example given in this appendix, the HCM 2000 level of service method is used. The HCM 2010 method (Transportation Research Board 2010) uses delay thresholds which are the same as in the HCM 2000 method, but assigns LOS F when the degree of saturation is greater than 1.0 (oversaturated conditions) irrespective of delay. For this example, the results do not differ if the HCM 2010 method is used. For further guidance, refer to Part 3 of the Guide to Traffic Management (Austroads 2017c).

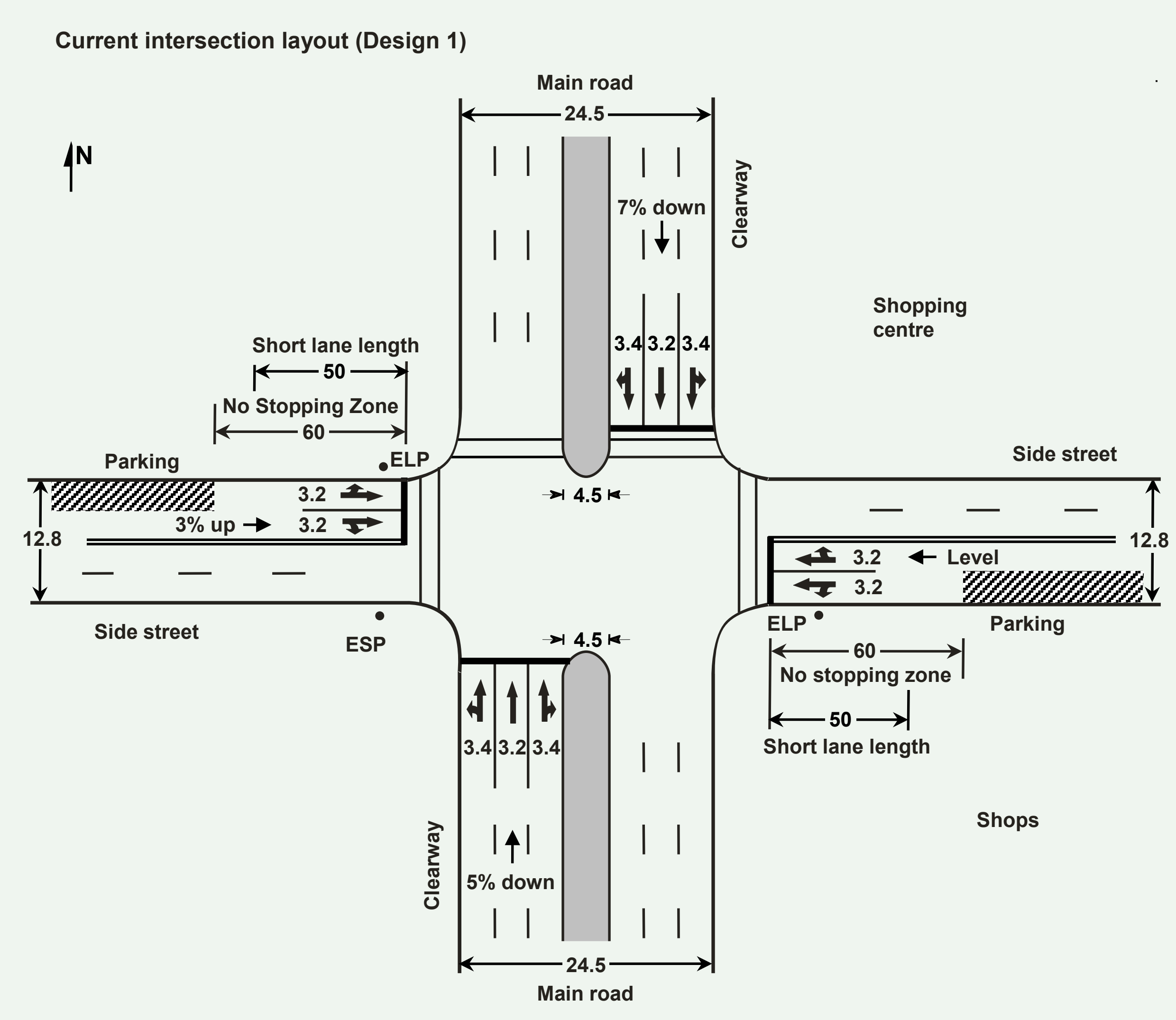
E.3 Existing Geometry and Phasing

E.3.1 Description and Input Data for Design 1

The current intersection layout (Design 1) is shown in Figure E 1. The North-South road (Main Road) has three-lane approaches with median and clearway conditions, whereas the East-West road (Side Street) has two-lane approaches without median and with parking allowed up to 60 m from the stop line (corresponding short lane lengths of 50 m are specified). All approaches have shared left turn and right turn lanes, and all lanes have normal stop lines (no slip lanes or continuous lanes).

Signalised crossings exist in front of all intersection legs except South. Other details such as lane widths, grades, kerb-to-kerb road widths, electric supply pole (ESP), electric light pole (ELP) and so on are shown in Figure E 1 .

Figure E 1: Current intersection layout (Design 1)



The existing intersection is two-phase operation with filter right turns as shown in Figure E 2. Peak hour traffic volumes for each approach and pedestrian volumes for each crossing are shown in Figure E 3.

The filter right turn movements from both North and South approaches encounter heavy opposing flows, and the right turn movement from North has high volume.

The site has a crash history of eight right-angle collisions and two ‘right turn with opposing-through’ collisions, and the number of crashes has been increasing in recent years. This trend is in line with increased right turn volume from the North resulting from the expansion of the shopping centre.

Figure E 2: Current signal phasing (Design 1)

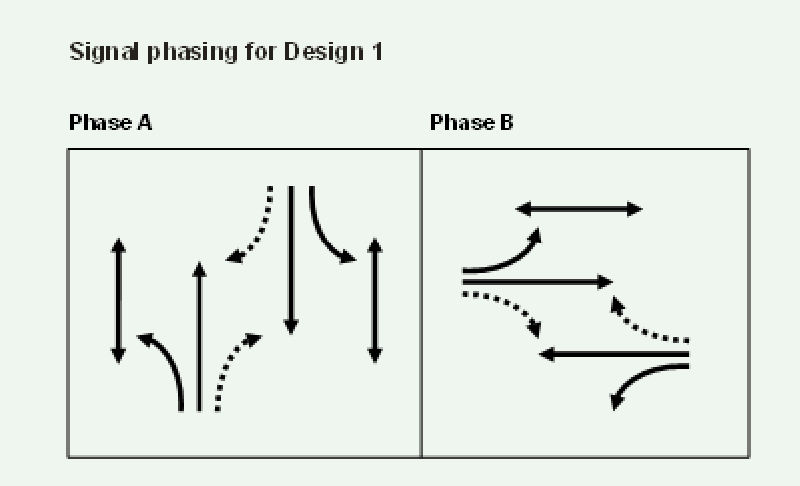
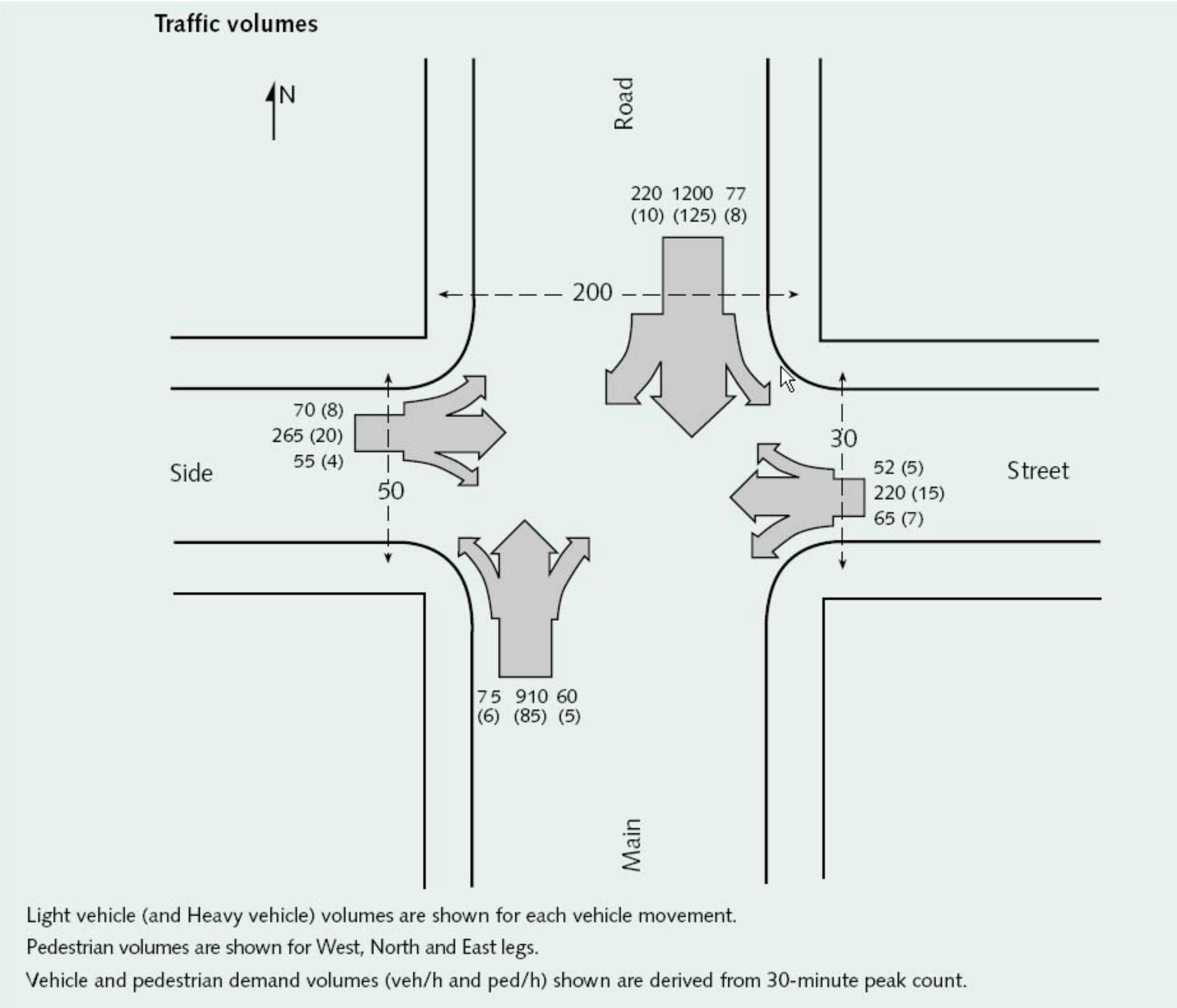


Figure E 3: Current traffic volumes (Design 1)



The two-phase arrangement can no longer cater for right turn volumes against heavy opposing through traffic flows, as evident by very long delays experienced by right turning vehicles from the North approach in particular. The current conditions (Design 1) will be analysed with this problem in mind, and then improvements to the intersection layout and signal phasing will be sought in order to improve the intersection safety and efficiency substantially (Design 2) as discussed in Part 6 of the Guide to Traffic Management (Austroads 2019c).

Various input data for Design 1 analysis are determined as follows:

1. The volumes in Figure E 3 are peak 30-minute values though given as hourly flow rates (i.e. twice the values of 30-minute volume counts). Therefore, Unit Time for Volumes is specified as 60 minutes, Peak Flow Period for performance calculations is specified as 30 minutes, and the Peak Flow Factor values are specified as 1.00.
2. There are no measured saturation flows available, and hence they will be estimated by the program. The site is in a suburban shopping environment. Basic saturation flows of 1950 and 1800 through car units per hour are considered to be appropriate for the North-South and East-West roads, respectively.
3. Due to wide median strips on South and North approaches, Free Queue values of 1 vehicle are specified for right turns in shared lanes. This means that one vehicle can queue away from the lane without interrupting the flow of the through movement which shares the lane (the second right turning vehicle would block the through traffic).
4. The intersection is in a 60 km/h speed limit zone. All approach and exit speeds are therefore specified as 60 km/h. All approach distances are specified as 500 m.
5. Yellow Time and All-Red Time values are determined using the method described in Appendix G.4.6. Yellow Times (ty) are calculated using Equation A2 with vD = 60 km/h, tr = 1.0 s, ad = 3.0 m/s2 and the grades shown in Figure E 1. The resulting Yellow Times are calculated as ty = 4.3 s for South, 4.6 s for North, 3.8 s for East and 3.5 s for West approaches. Intersection widths used for All-Red Time (tar) calculations are 13 m for North-South movements and 25 m for East-West movements, and the corresponding All-Red Times from Equation A3 are tar = 0.8 and 1.5 s, respectively. The following values are used as input (rounded to nearest half second):
   - Phase A (North-South movements): ty = 5.0 s, tar= 1.0 s
   - Phase B (East-West movements): ty = 4.0 s, tar= 1.5 s

   Thus, Intergreen Times are 6.0 seconds ($I = t_y + t_{ar}$) for the North-South movements and 5.5 s for the East-West movements.
6. The minimum green times are 8 seconds for Phases A and B (Table G 1), subject to pedestrian minimum time requirements discussed in point 8 below. Normal start loss values are 3 seconds. Left turning and right turning vehicles that conflict with pedestrian movements are assumed to experience a further 8 seconds delay. Therefore, the start loss values for turning vehicles (except left turns from East and right turns from West) will be 11 seconds. This will impact traffic performance significantly but will have less effect on right turn traffic since start losses due to opposing traffic queue clearance intervals are longer than 11 seconds.
7. The pedestrian Walk Time is selected as 6 seconds for all movements (Walk Times are not extended with parallel vehicle green times). The pedestrian clearance times are determined by SIDRA INTERSECTION using Equation A5 with pedestrian clearance speed of 1.2 m/s (default). Clearance distances of 14 m for North-South movements and 26 m for East-West movements (including both carriageways and the median width as applicable) are specified.
8. Minimum time requirements for pedestrians are determined as the sum of Walk Time and Clearance 1 Time (Figure G 2). Clearance 1 Time is determined as the Total Clearance Time less Clearance 2 Time (overlap with the Intergreen Time). The SIDRA INTERSECTION default value of 2 seconds Clearance 2 Time is used.
9. The resulting ‘Pedestrian Minimum Green’ times are 16 seconds for North-South movements and 26 seconds for East-West movements. The SIDRA INTERSECTION method for actuated signals may use a smaller ‘average’ minimum pedestrian time requirement so as to allow for signal cycles with no pedestrian demand. This is likely to come into effect with low pedestrian volumes on the crossings in front of the East and West approaches.

10. Default values of actuated signal settings (maximum green and gap settings) will be used. Effective detection zone length is 4.5 m for all lanes. Due to the phasing arrangement without any arrow-controlled right turns in Design 1, Maximum Green Setting = 50 seconds and Gap Setting = 2.5 seconds will be used for all movements.
11. Actuated coordinated signals are assumed. Arrival types of 5 (‘Highly favourable’ progression quality) for the through movement on the North approach, and 4 (‘Favourable’ progression quality) for the through movement on the South approach are specified.

E.3.2 Analysis Results for Design 1

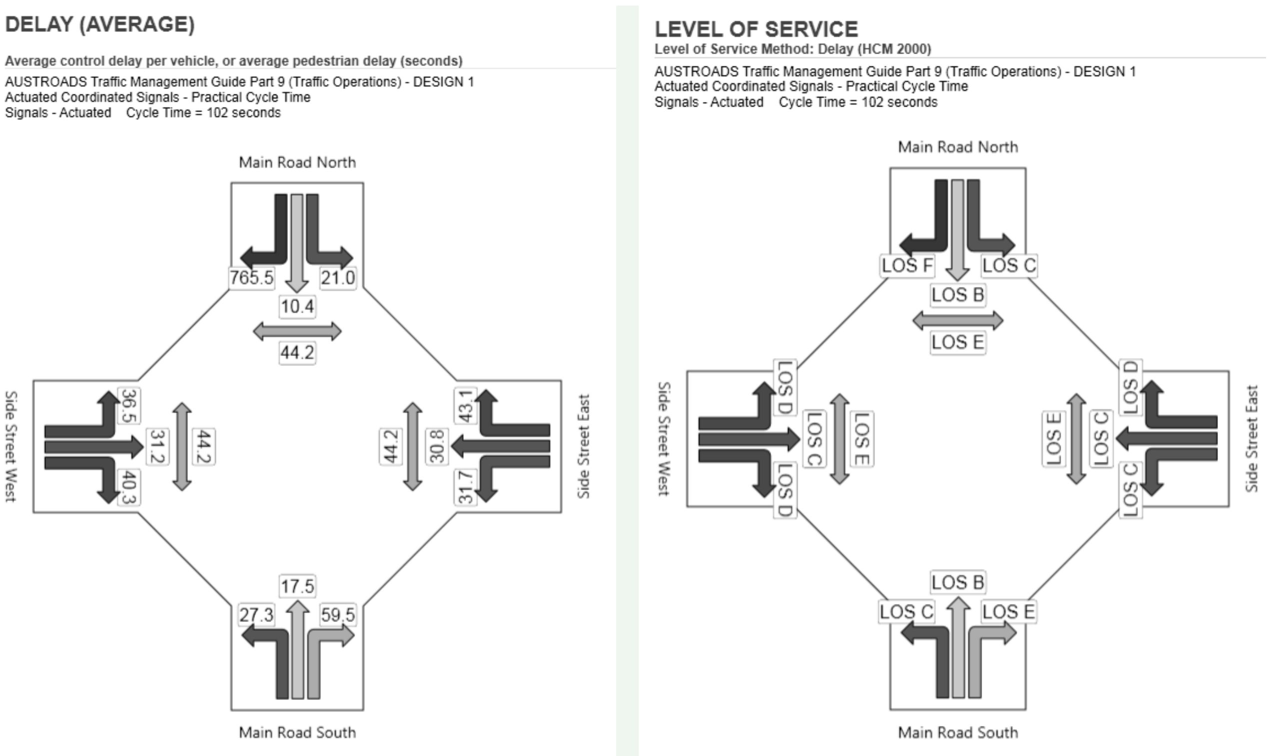
With the default actuated signal settings, an average cycle time of 102 seconds is estimated with displayed green times of 50 seconds for Phase A (maximum), and 40 seconds for Phase B. Highly oversaturated conditions, and therefore very long delays (level of service F), are estimated for the filter right turn movement from North as seen in Figure E 4 and Figure E 5. All other movements appear to operate satisfactorily, with the exception of the right turn movement from South (level of service E).

From Figure E 5, the right turn lanes on North and South approaches are seen to be operating as de facto exclusive lanes (right turns only) due to much longer delays experienced in these lanes (i.e. no through traffic uses these lanes which are specified as shared through and right turn traffic lanes). This indicates inefficient use of the road space available.

Optimisation of cycle time (as coordinated actuated signals) for minimising the average intersection delay value indicates that the performance of right turn movements can be improved significantly at an optimum cycle time of 75 seconds (displayed green times of 39 seconds for Phase A, and 24 seconds for Phase B). However, the right turn movement from the North approach is still highly oversaturated (average delay = 401.2 seconds). Furthermore, the coordination requirements may not allow the use of a shorter cycle time.

These results confirm the need for improvements to the intersection layout and signal phasing to cater for the right turn movement from the North approach in particular.

Figure E 4: Average delay and level of service estimates for Design 1 (based on default actuated signal settings)



	South	East	North	West	Intersection
Delay (Average)	20.6	32.9	116.8	33.4	67.6
LOS	C	C	F	C	E

	South	East	North	West	Intersection
LOS	C	C	F	C	E

Source: Akcelik and Associates (2009), ‘Intersection output provided by source’.

Figure E 5: Lane flow, capacity and performance results for Design 1 (based on default actuated signal settings)

LANE SUMMARY

Site: Austroads TM9 Design 1 - VA - Prac Cycle

AUSTROADS Traffic Management Guide Part 9 (Traffic Operations) - DESIGN 1
Actuated Coordinated Signals - Practical Cycle Time
Signals - Actuated Cycle Time = 102 seconds

Lane Use and Performance

	Demand Flows L veh/h	Demand Flows T veh/h	Demand Flows R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Main Road South																
Lane 1	81	443	0	524	8.4	856	0.613	79[5]	20.1	LOS C	16.3	122.1	500	–	0.0	0.0
Lane 2	0	552	0	552	8.5	901	0.613	79[5]	16.5	LOS B	15.8	118.6	500	–	0.0	0.0
Lane 3	0	0	65	65	7.7	83	0.780	100	59.5	LOS E	3.5	26.1	500	–	0.0	0.0
Approach	81	995	65	1141	8.4		0.780		20.6	LOS C	16.3	122.1				
East: Side Street East																
Lane 1	72	81	0	153	7.9	297[1]	0.517	100	27.1	LOS C	5.1	38.2	50	Parking	0.0	0.0
Lane 2	0	154	57	211	7.0	407	0.517	100	37.1	LOS D	9.0	66.5	500	–	0.0	0.0
Approach	72	235	57	364	7.4		0.517		32.9	LOS C	9.0	66.5				
North: Main Road North																
Lane 1	85	606	0	691	9.4	860	0.803	45[5]	13.4	LOS B	21.1	159.6	500	–	0.0	0.0
Lane 2	0	719	0	719	9.4	896	0.803	45[5]	8.8	LOS A	19.0	143.5	500	–	0.0	0.0
Lane 3	0	0	230	230	4.3	130	1.773	100	765.5	LOS F	54.9	398.4	500	–	0.0	0.0
Approach	85	1325	230	1640	8.7		1.773		116.8	LOS F	54.9	398.4				
West: Side Street West																
Lane 1	78	72	0	150	8.7	271[1]	0.553	100	32.4	LOS C	5.5	41.4	50	Parking	0.0	0.0
Lane 2	0	213	59	272	7.0	492	0.553	100	34.0	LOS C	11.3	83.8	500	–	0.0	0.0
Approach	78	285	59	422	7.6		0.553		33.4	LOS C	11.3	83.8				
Intersection				3567	8.4		1.773		67.6	LOS E	54.9	398.4				

Level of Service (LOS) Method: Delay (HCM 2000).
Lane LOS values are based on average delay per lane.
Intersection and Approach LOS values are based on average delay for all lanes.
SIDRA Standard Delay Model used.

1 Reduced capacity due to a short lane effect
5 Lane underutilisation determined by program

Source: Akcelik and Associates (2009), 'Intersection output provided by source'.

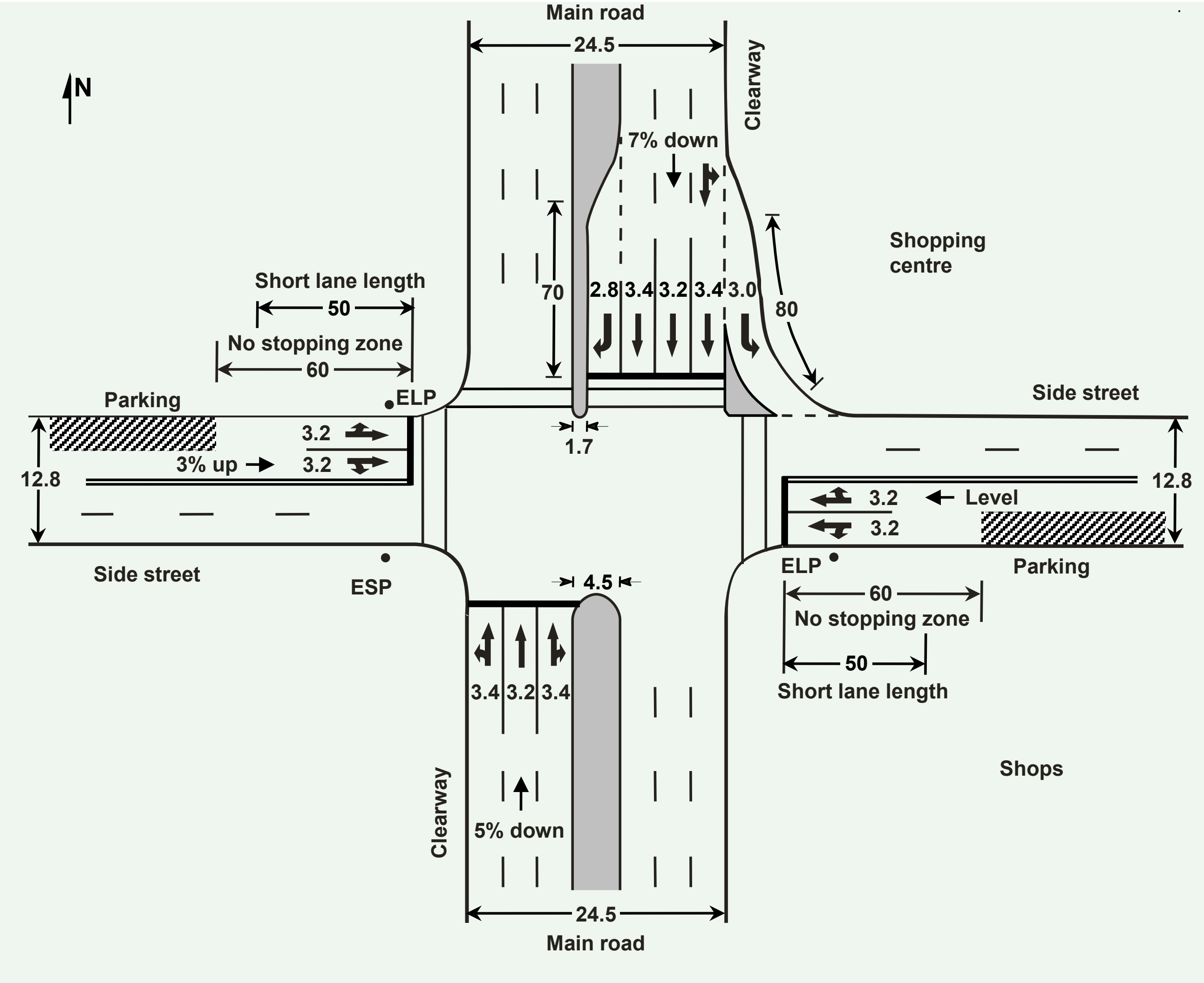
E.4 Proposed Geometry and Phasing

E.4.1 Description and Input Data for Design 2

The proposed intersection layout (Design 2) is shown in Figure E 6. It is similar to that of Design 1, with the exception of the following changes made to the North approach:

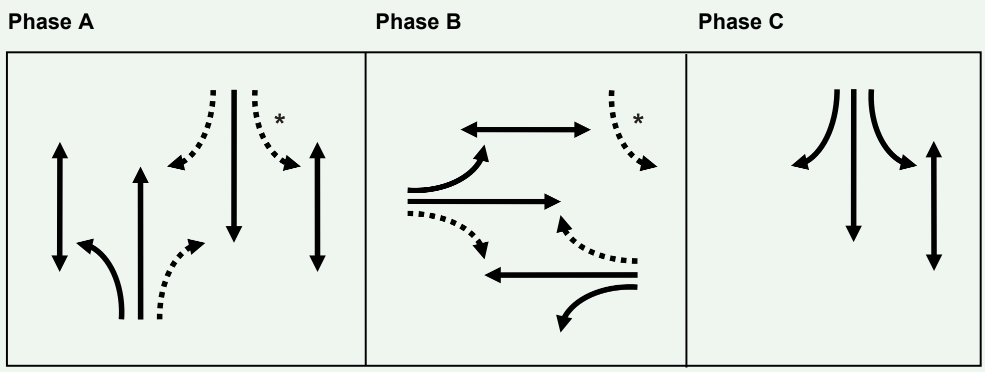
1. An exclusive right turn lane 2.8 m wide and 70 m long (short lane) is provided.
2. The median strip is reduced from 4.5 m to 1.7 m wide.
3. A left turn slip lane 3.0 m wide and 80 m long (short lane) is provided.
4. The pedestrian crossing between the footpath and the traffic island is not signalised. If a Zebra (unsignalised) crossing is used, the effect on left turns using the slip lane could be analysed using SIDRA INTERSECTION.

Figure E 6: Proposed intersection layout (Design 2)



The proposed signal phasing system is shown in Figure E 7. Because the exclusive right turn lane added to the North approach will be arrow controlled, a leading right turn sequence is used as the opposing filter right turn has been retained (Phase C added). A lagging right turn sequence has safety problems in this case (Section 6.5.3). Had the right turn volume from the South approach been considerably higher, a diamond overlap phase design would have been assessed (Section 6.5.3). This would have required an exclusive right turn lane to be provided on the South approach as well.

Figure E 7: Signal phasing for Design 2



* Left turn movement from North approach gives way to opposing through and right turn movements in Phases A and B

The left turn movement from north (slip lane) gives way to right turns from south in Phase A, and to through traffic from west in Phase B. This movement is designated as undetected, and therefore, will not affect signal timings.

The right turn movement from north receives two distinct green periods, namely unopposed during Phase C and opposed during Phase A, stopping during the intergreen time between Phases C and A. On the other hand, the through movement from north has a single green period although it runs during both Phases C and A (it is not stopped during the intergreen time between Phases C and A). However, if the design permitted Phase A to be skipped allowing signal control to change from Phase C to Phase B, then adequate clearance should be provided during Phase C for both the North Right Turn and North Through movements. This may require further consideration on a site-by-site basis.

The intergreen time for Phase C is calculated on the basis of the conflict between the right turn movement from North clearing the intersection and the pedestrian movement in front of the West approach starting. Negotiation radius for this movement is measured as 15 m, and the distance is calculated as 24 m.

Using t_r = 1.0 s, a_d = 3.0 m/s^2, v_D = 60 km/h and G = –0.07 in Equation A2, yellow time is calculated as t_y = 4.6 s. Using L_C = 24 m in Equation A3, all-red time (for 60 km/h zone) is found as t_{ar} = 1.4 s. The following values are used as input (rounded to the nearest half second):

- Phase A (North - South movements): t_y = 5.0 s, t_{ar} = 1.0 s
- Phase B (East-West movements): t_y = 4.0 s, t_{ar} = 1.5 s
- Phase C (North Leading Right Turn): t_y = 5.0 s, t_{ar} = 1.5 s.

Thus, Intergreen Times are 6.0 s ($I = t_y + t_{ar}$) for the North-South movements, 5.5 s for the East-West movements and 6.5 s for the North Leading Right Turn.

Minimum green times for Phases A and B are 8 seconds as in Design 1, and minimum green time for Phase C is chosen as 6 seconds (Table G 1). Minimum pedestrian time requirements are not changed as a result of the changes to intersection geometry.

The additional start loss of 8 seconds is removed from the left turn movement from North. It is retained for the right turn movement from North in Phase A, but there is no additional start loss for this movement in Phase C.

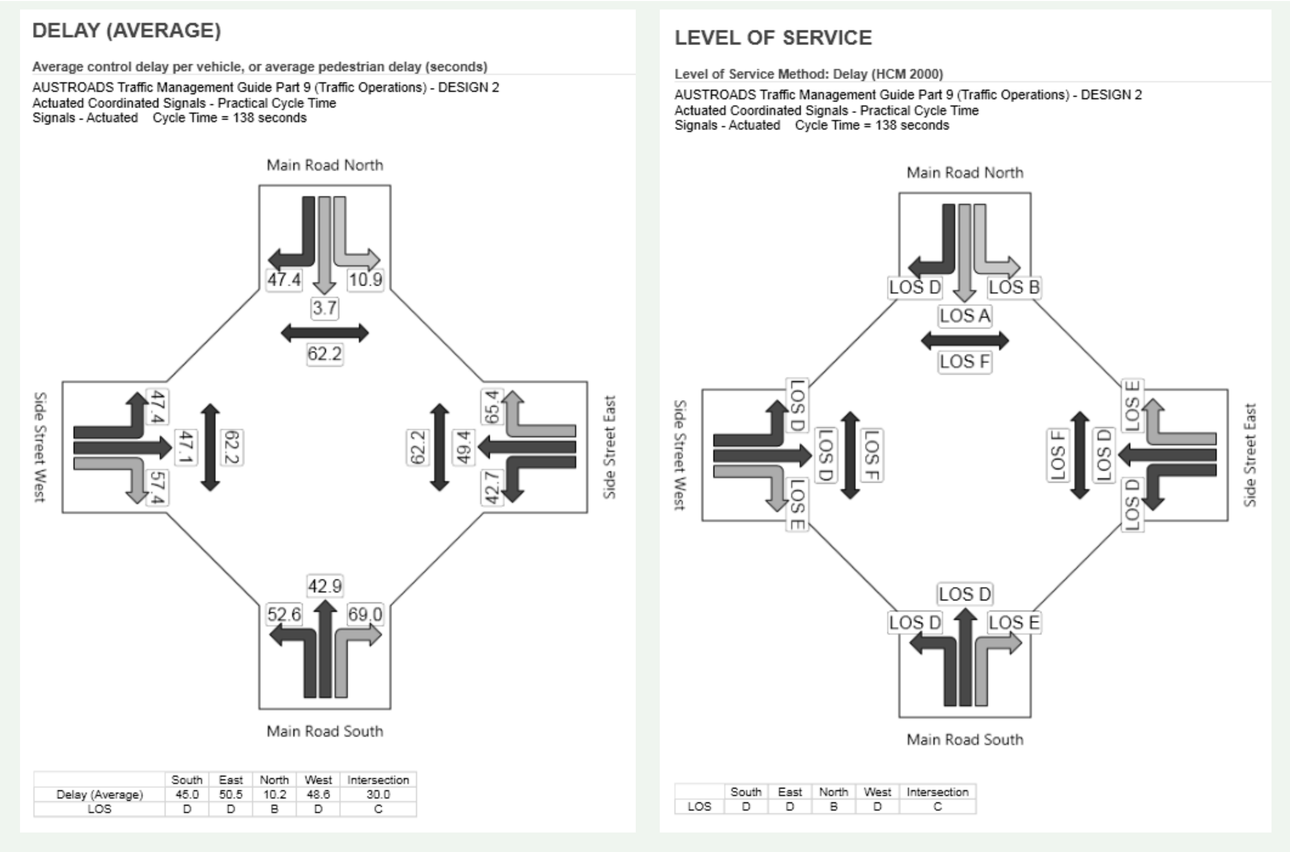
For Phase C (arrow-controlled right turn), maximum green setting = 20 seconds and gap setting = 2.0 seconds will be applicable (default values). Signal coordination data are unchanged.

E.4.2 Analysis Results for Design 2

With the default actuated signal settings, an average cycle time of 138 seconds is estimated with displayed green times of 50 seconds each for Phases A and B, and 20 seconds for Phase C. This is the maximum cycle time that results from all critical movements requiring maximum green times.

The intersection performance under this set of timings (long cycle time) is not satisfactory as seen in Figure E 8. Although satisfactory performance is achieved for the right turn movement from North, all pedestrian movements and the right turn movements from other approaches are seen to experience long delays (levels of service F for pedestrians and E for those right turn movements).

Figure E 8: Average delay and level of service estimates for Design 2 (default maximum green settings)



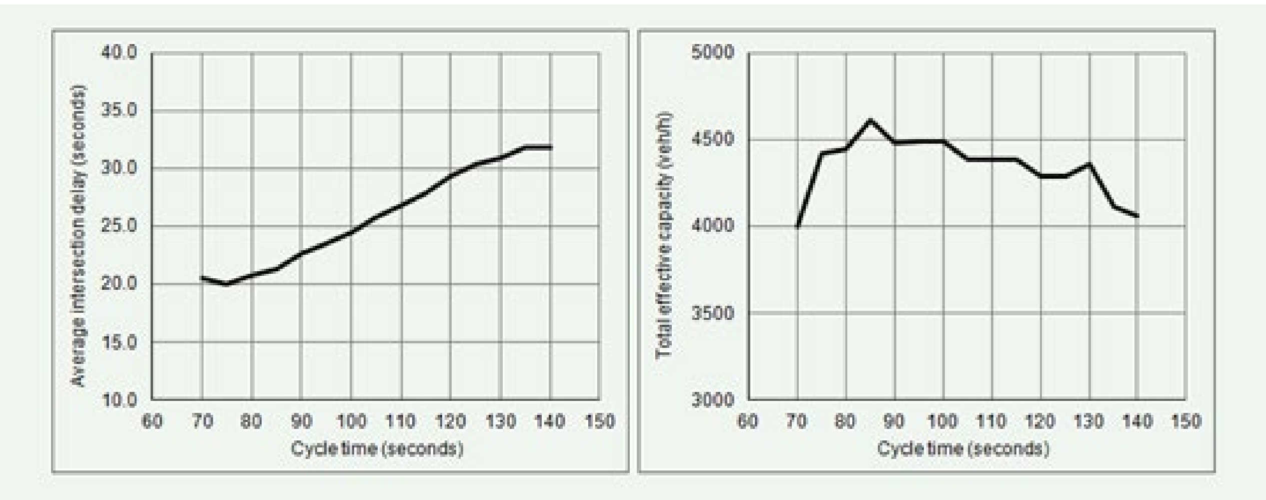
	South	East	North	West	Intersection
Delay (Average)	45.0	50.5	10.2	48.6	30.0
LOS	D	D	B	D	C

	South	East	North	West	Intersection
LOS	D	D	B	D	C

Source: Akcelik and Associates (2009), 'Intersection output provided by source'.

Figure E 9 indicates optimum cycle time solutions for Design 2. For cycle times in the range 70 to 140 seconds, delay is minimised at a cycle time of 75 seconds and capacity is maximised at a cycle time of 85 seconds. These solutions indicate satisfactory results for all movements (level of service D or better is obtained for all vehicle and pedestrian movements). Significant decreases in capacity with longer cycle times are due to the existence of short lanes, filter right turns and lane blockages (by left turns waiting for pedestrians, and filter right turns waiting for gaps).

Figure E 9: Average intersection delay and total effective capacity versus cycle time for Design 2

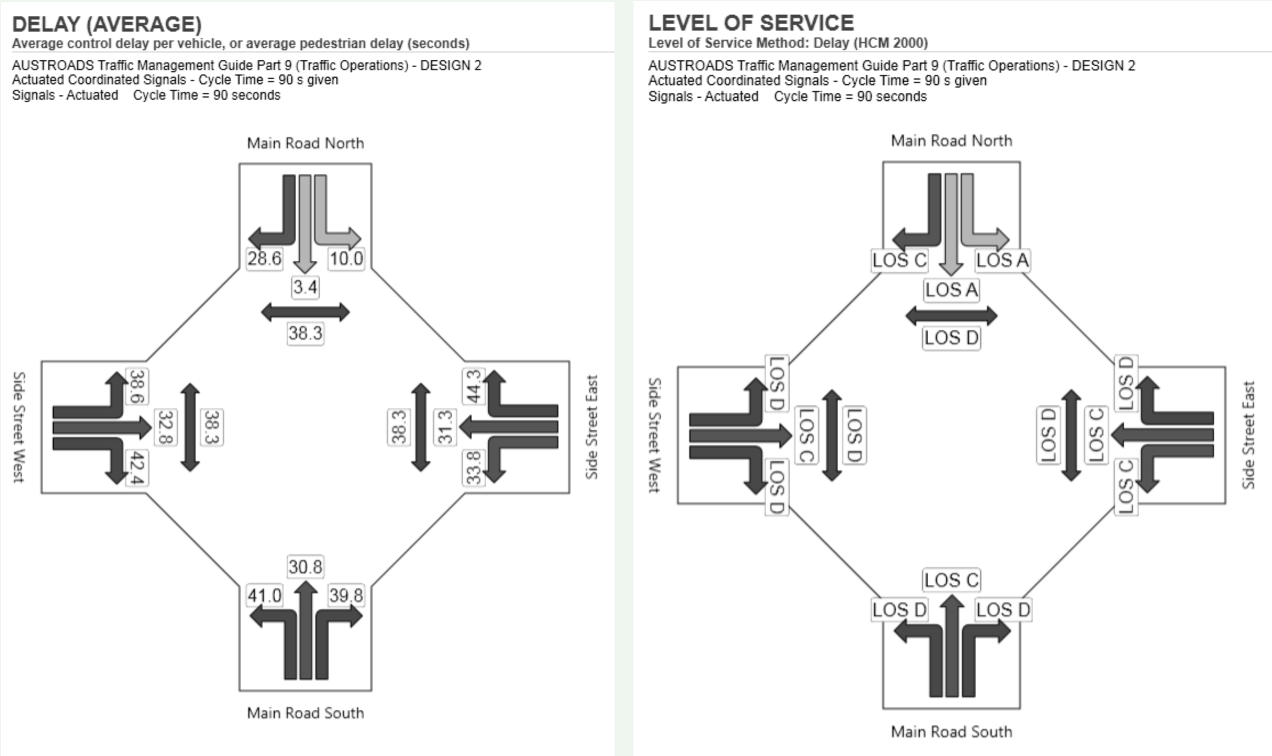


Source: Akcelik and Associates (2009), 'Intersection output provided by source'.

Considering coordinated signal operations (on the basis that this is the critical intersection in the signal coordination area), a cycle time around 80 to 110 seconds would be acceptable for Design 2. Using 70% of default maximum green settings (35 seconds for through and left turn movements and 14 seconds for arrow-controlled right turn movements), a cycle time of 102 seconds is obtained with displayed green times of 35 seconds each for Phases A and B, and 14 seconds for Phase C. The performance results under these timings are generally satisfactory except level of service E for all pedestrian movements (average delay 44.2 seconds).

Given the above results, a cycle time of 90 seconds is specified for coordinated signal operation. Maximum green settings of 35 seconds for through and left turn movements and 14 seconds for the arrow-controlled right turn movement (70% of default values) are used. The resulting displayed green times are 30 seconds each for Phases A and B and 12 seconds for Phase C. The performance results under these timings are shown in Figure E 10 and Figure E 11. The largest degree of saturation is 0.77, average delay is 21.2 seconds for all vehicles (level of service C) and 38.3 seconds for all pedestrians (level of service D).

Figure E 10: Average delay and level of service estimates using a cycle time of 90 seconds for Design 2



	South	East	North	West	Intersection
Delay (Average)	32.1	33.8	7.3	35.2	21.2
LOS	C	C	A	D	C

	South	East	North	West	Intersection
LOS	C	C	A	D	C

Source: Akcelik and Associates (2009), 'Intersection output provided by source'.

Figure E 11: Lane flow, capacity and performance results using a cycle time of 90 seconds for Design 2

LANE SUMMARY

Site: Austroads TM9 Design 2 - VA - c=90 given

AUSTROADS Traffic Management Guide Part 9 (Traffic Operations) - DESIGN 2
Actuated Coordinated Signals - Cycle Time = 90 s given
Signals - Actuated Cycle Time = 90 seconds

Lane Use and Performance

	Demand Flows L veh/h	Demand Flows T veh/h	Demand Flows R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
South: Main Road South																
Lane 1	81	343	0	424	8.3	549	0.773	100	34.0	LOS C	16.6	124.8	500	–	0.0	0.0
Lane 2	0	474	0	474	8.5	613	0.773	100	29.4	LOS C	17.9	134.3	500	–	0.0	0.0
Lane 3	0	178	65	243	8.3	314	0.773	100	33.8	LOS C	9.7	72.7	500	–	0.0	0.0
Approach	81	995	65	1141	8.4		0.773		32.1	LOS C	17.9	134.3				
East: Side Street East																
Lane 1	72	105	0	177	7.7	303 [1]	0.586	100	28.7	LOS C	5.9	43.8	50	Parking	0.0	0.0
Lane 2	0	130	57	187	7.1	318	0.586	100	38.7	LOS D	7.6	56.4	500	–	0.0	0.0
Approach	72	235	57	364	7.4		0.586		33.8	LOS C	7.6	56.4				
North: Main Road North																
Lane 1	85	0	0	85	9.4	990 [1]	0.086	100	10.0	LOS A	0.7	5.5	80	Turn Bay	0.0	0.0
Lane 2	0	443	0	443	9.4	985	0.450	100	3.4	LOS A	3.6	27.1	500	–	0.0	0.0
Lane 3	0	439	0	439	9.4	975	0.450	100	3.4	LOS A	3.5	26.8	500	–	0.0	0.0
Lane 4	0	443	0	443	9.4	985	0.450	100	3.4	LOS A	3.6	27.1	500	–	0.0	0.0
Lane 5	0	0	230	230	4.3	336	0.686	100	28.6	LOS C	5.8	42.1	70	Turn Bay	0.0	0.0
Approach	85	1325	230	1640	8.7		0.686		7.3	LOS A	5.8	42.1				
West: Side Street West																
Lane 1	78	99	0	177	8.4	278 [1]	0.637	100	33.8	LOS C	6.4	48.3	50	Parking	0.0	1.9
Lane 2	0	186	59	245	7.0	385	0.637	100	36.2	LOS D	9.8	73.0	500	–	0.0	0.0
Approach	78	285	59	422	7.6		0.637		35.2	LOS D	9.8	73.0				
Intersection				3567	8.4		0.773		21.2	LOS C	17.9	134.3				

Level of Service (LOS) Method: Delay (HCM 2000).
Lane LOS values are based on average delay per lane.
Intersection and Approach LOS values are based on average delay for all lanes.
SIDRA Standard Delay Model used.

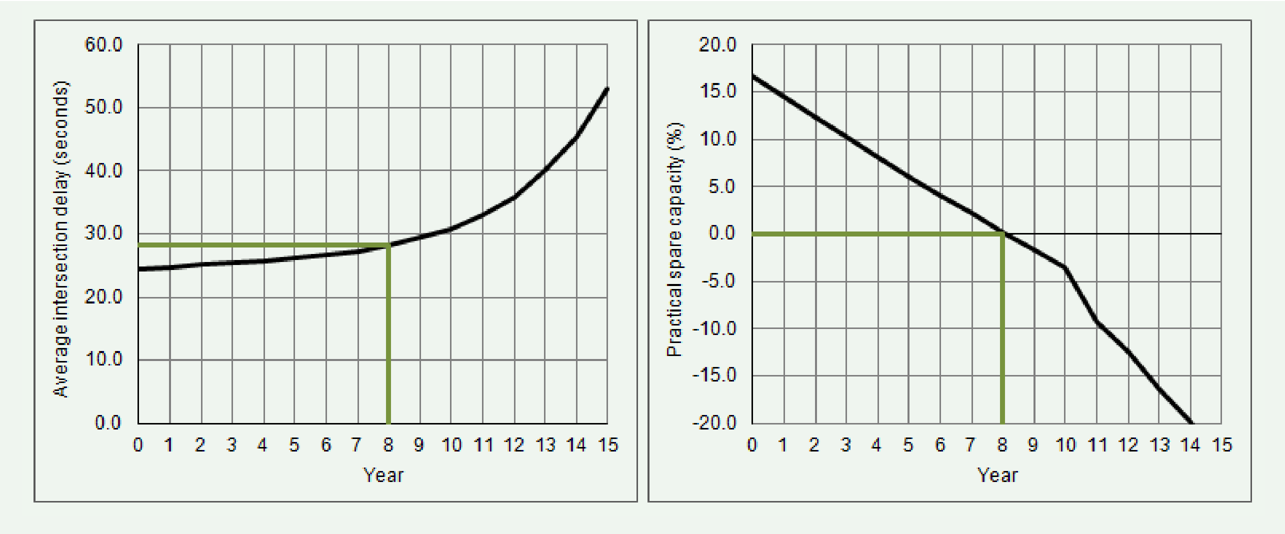
1 Reduced capacity due to a short lane effect

Source: Akcelik and Associates (2009), 'Intersection output provided by source'.

Finally, a design life analysis is carried out using the reduced maximum green settings (70% of default values). All demand flows are increased from current levels by applying a traffic growth rate of 2% per year for all movements (compound growth method used). Signal timings are calculated under each demand flow scenario. As seen in Figure E 12, the results indicate that the intersection would be operating at practical capacity after eight years. This means that traffic demand could increase by 17.2% before the intersection reaches the point when the spare capacity is zero, i.e. the intersection degree of saturation equals the practical (target) degree of saturation of 0.90.

Based on the above analysis results, it may be concluded that Design 2 provides a satisfactory solution to the problems experienced with Design 1. It is important to note that the performance of this design would deteriorate significantly if cycle times above 100 seconds resulted from the use of long maximum green settings.

Figure E 12: Average intersection delay and percentage spare capacity versus future years for Design 2 (with maximum green settings at 70% of default values)



Source: Akcelik and Associates (2009), 'Intersection output provided by source'.

E.5 Implementation of Proposed Design

E.5.1 Provision of Signal Hardware and Location

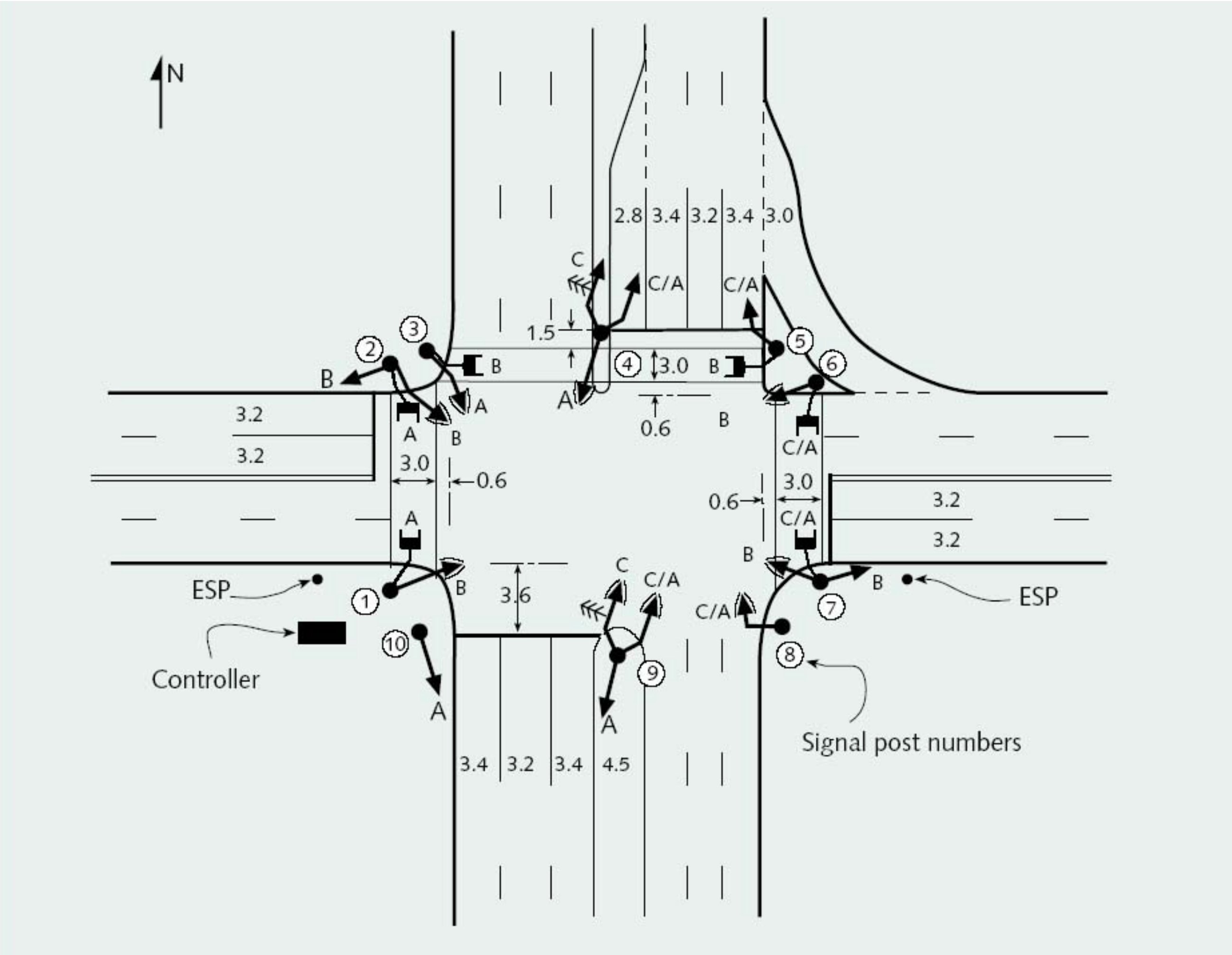
Following the signal timing and performance analyses in the previous sections, the intersection geometry and phasing design can be finalised, and the necessary signal hardware such as signal faces, posts, mast arms, controller and detectors, as well as the line markings and signposting, may be included on the base plan of Design 2. For detailed information, see Part 10 of the Guide to Traffic Management (Austroads 2019d) for the use and location of this equipment, Section 6.8 for the basic logic and installation of detectors, and Part 10 of the Guide to Traffic Management (Austroads 2019d) for various types of pavement marking and signposting.

Figure E 13 shows the line marking, signal face locations and provision of some accessories. The following discussions are based on this figure.

Signal faces

Since the movements on the east, south and west approaches do not include any arrow-controlled turning movements; the basic three-aspect signal display is used. However, as the signal faces for the north approach are required to provide for a leading right turn phase, a six-aspect multicolumn signal face is used. This consists of a column of three-aspect (green, yellow and red) right turn arrows in addition to the basic three-aspect signals (Part 10 of the Guide to Traffic Management, Austroads 2019d). This operation could also be implemented using a five-aspect two-column signal face with green and yellow right turn arrows only (Part 10 of the Guide to Traffic Management, Austroads 2019d). In the case of three-aspect right turn arrows, red-arrow drop out method is used to achieve filter right turns in Phase A as allowed by the adjacent green circle displays (Section 6.5.3).

Figure E 13: Signal face locations for Design 2



Number of signal faces

- East and west approaches: Three signal faces (primary, secondary and tertiary) are provided. The green circle is displayed during Phase B.
- North approach: Four signal faces (primary, dual primary, secondary, and tertiary) are provided. The primary and tertiary signal faces are three-aspect circles. The dual primary and secondary signal faces are six-aspect with three-aspect circles and three-aspect arrows. As the medians are of sufficient width, these signal faces are on posts located in the medians. The green arrow is displayed in Phase C only. The green circle is displayed in both A and C Phases and the C/A intergreen.
- South approach: Four signal faces (primary, dual primary, secondary, and tertiary) are provided. As the medians are of sufficient width, these signal faces are on posts located in the medians. All signal faces are three-aspect circles. The green circle is displayed in Phase A only.
- Pedestrian signals: Only one pedestrian signal face is required at each end of the signalised crossing as the crossing width and distance criteria are satisfied (Part 10 of the Guide to Traffic Management) (Austroads 2019d). Note that the east-west crossing distance is close to the limit value of 25 m. Pedestrian signal faces display the green Walk signal during the appropriate Phases C/A, A or B (Figure E 7 and Figure E 13).

Size of signal aspects

- Only 200 mm aspects are used as recommended in Part 10 of the Guide to Traffic Management (Austroads 2019d) since there are no grounds for providing 300 mm signals.

Use of mast arm

- The use of mast arm or overhead signal faces is not warranted at this site. For the south and north approaches, the dual primary signal face can be accommodated on the median islands as its width is greater than the 1.5 m recommended for dual column aspects of 200 mm size.

Target boards

- All vehicle signal faces are provided with a target board, appropriate to the signals being used.

Visors and louvres

- Closed visors are to be provided on all secondary and tertiary signal faces except the three-aspect right-arrow signal faces (Part 10 of the Guide to Traffic Management). The use of louvres is not warranted in this case.

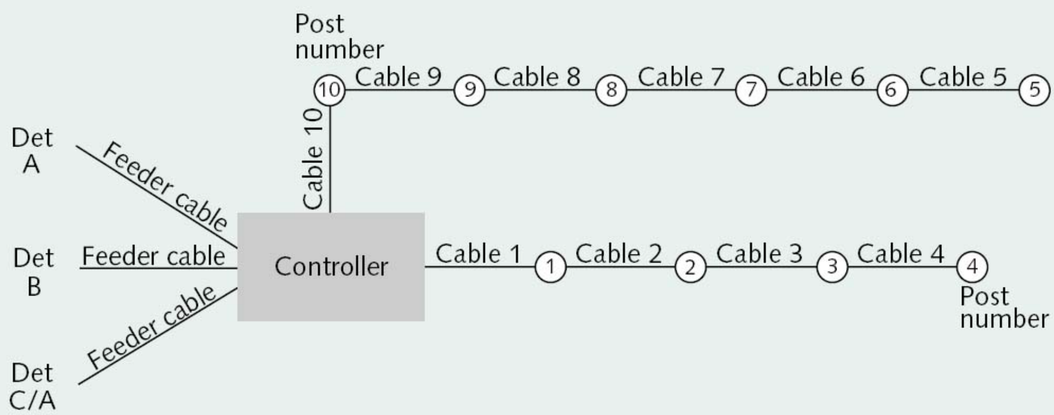
Location of controller housing and signal posts

- The controller should be located in an unexposed position in close proximity to the intersection and available power supply. In Figure E 13, this is located on the south-west corner. The posts are numbered sequentially (1 to 10) in a clockwise manner for the identification used in the cable connection diagram. Note that the number of posts has been minimised by accommodating the various signals where practicable on a common post.

E.5.2 Cable Connection Design

The cable layout for the intersection is prepared next, according to the general requirements indicated in Appendix F. The layout, which uses the open-loop system, is shown in Figure E 14. Two parallel circuits are set up to connect all signal faces and pedestrian push-buttons to the controller.

Figure E 14: Typical cable layout for Design 2



An optional cable can be added between Posts 4 and 5. This cable is available to restore the service quickly in the event of a breakage elsewhere in the loop.

A closed-loop system may be achieved by adding a cable between Posts 4 and 5. This helps to restore the service quickly in the event of a breakage elsewhere in the loop. However, this cable would not normally be terminated at Post 5 as it would affect the lamp monitoring.

The vehicle detectors are connected to the controller separately via screened feeder cables. The cable size is chosen to provide sufficient cores to cater for signal requirements with adequate spares.

The circuits are arranged to achieve the most economical solution in terms of cable size and length, and the associated costs of ducting under the prevailing site conditions and existing services. Adequate spares in cores must be provided in each cable for possible future expansion. The cable size is chosen to provide sufficient cores to cater for signal requirements with adequate spares.

In view of the above considerations, the first circuit caters for Posts 1 to 4; the second circuit caters for Posts 5 to 10.

E.5.3 Selection of Controller Settings

The results of the signal timing analysis for Design 2 (Appendix E.4) can be used in conjunction with the method described in Appendix G to determine initial controller settings.

Controller operation sheets

Controller operation sheets are used to record operational specifications and all related information including controller type, signal group allocation, detector map (layout and numbering), detector functions, phasing diagram, approach timing details, controller time settings including pedestrian time settings, signal coordination details, and special functions.

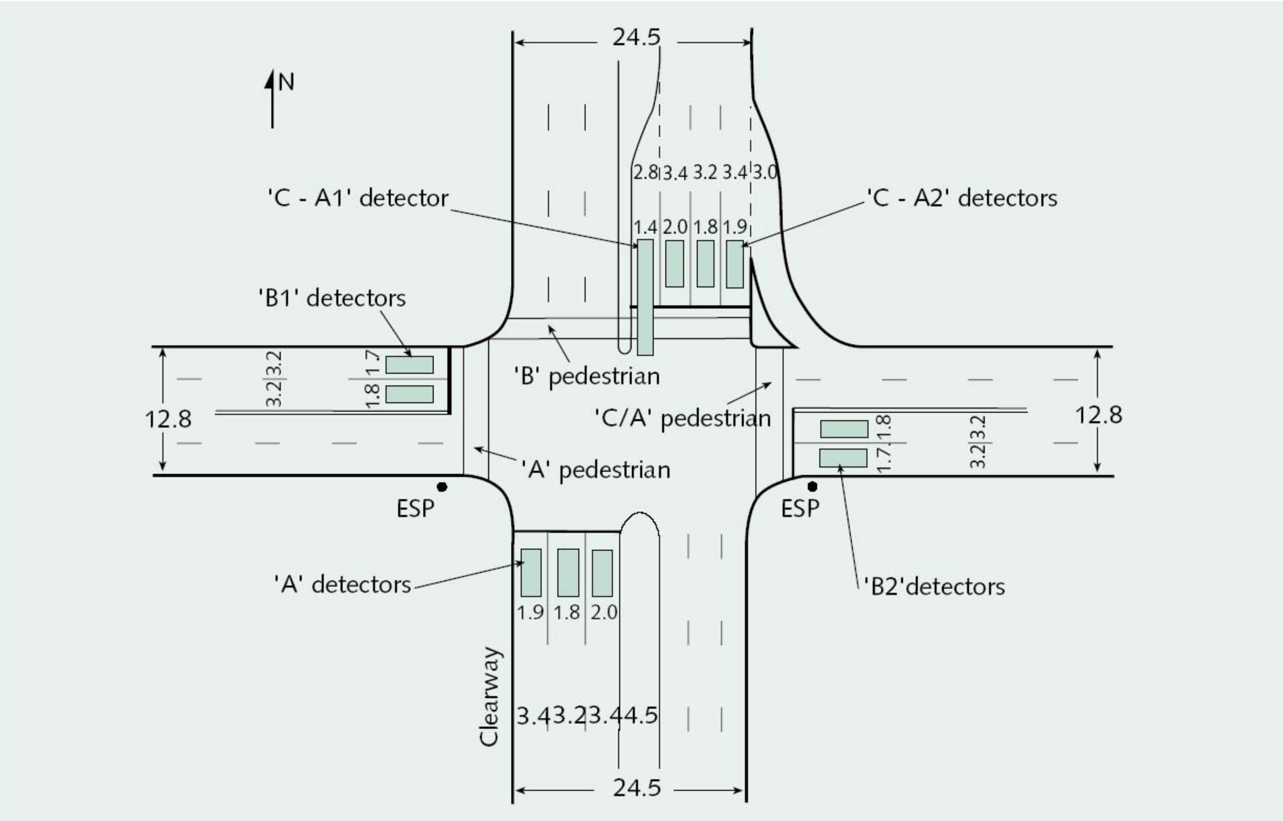
Utilising the controller operation sheets, a personality to adapt a controller to the intersection is prepared by use of a generation program specific to the brand and model of controller being used. These programs require considerable experience and expertise to implement effectively. The manufacturer or a professional with expertise in the particular controller being used should be consulted.

Detectors and approach timers

Detectors and approach timers must be decided before the controller settings are determined. These are detailed below:

1. All detectors are 4.5 m presence detectors located at the stop line in each lane, except for the C Phase right turn detector, which is an 11.0 m detector because both an arrow-controlled turn and a filter turn are provided (Figure E 15, also Figure E 15 in Section 6.8). Individual detector loops are labelled for identification purposes. Method of labelling varies from jurisdiction to jurisdiction and may reflect detector operational functions.
2. The approach timers are allocated as:
   - Phase A, approach timer 1: A detectors
   - Phase A, approach timer 2: C-A2 detectors
   - Phase B, approach timer 1: B1 detectors
   - Phase B, approach timer 2: B2 detectors
   - Phase C, approach timer 1: C-A1 detector (approach section)
   - Phase C, approach timer 2: C-A2 detectors.
3. Pedestrian features will be as follows:
   - Pedestrian feature number 1: C/A pedestrian
   - Pedestrian feature number 2: A pedestrian
   - Pedestrian feature number 3: B pedestrian.

Figure E 15: Location of detectors for Design 2



Timing card

A timing card is used to record controller settings. Part of a typical timing card completed for Design 2 is shown in Figure E 16. Values given in this figure are based on those used in the SIDRA INTERSECTION analysis for Design 2 where applicable. Dashes (-) have been used for those time settings that are not applicable. These should not be confused with zeros that, if used, would produce zero time settings.

Figure E 16: Phase and pedestrian time settings recorded on a typical timing card for Design 2

Controller time settings

Phase time settings

Time setting No.	Description	Limit	Phase A (1)	B (2)	C (3)	D (4)	E (5)	F (6)	G (7)
1	Red/yellow	5	-	-	-				
2	Late start	20	5	-	-				
3	Minimum green	20	8	8	6				
4	Increment	5	-	-	-				
5	Maximum initial green	40	-	-	-				
6	Maxmum extension green	90	27	27	8				
7	Early cut off	20	-	-	-				
8	Yellow	7	5.0	4.0	5.0				
9	All red	15	1.0	1.5	1.5				
10	Special all red	15	-	-	-				
11	Gap 1	10	2.5	2.5	2.0				
12	Gap 2	10	2.5	2.5	2.5				
13	Gap 3	10	-	-	-				
14	Gap 4	10	-	-	-				
15	Headway 1	5	0.7	0.7	0.6				
16	Headway 2	5	0.7	0.7	0.6				
17	Headway 3	5	-	-	-				
18	Headway 4	5	-	-	-				
19	Waste 1	50	4.0	4.0	2.0				
20	Waste 2	50	4.0	4.0	2.0				
21	Waste 3	50	-	-	-				
22	Waste 4	50	-	-	-				
Special all red sequences			-	-	-				
Prohibited sequences			-	A-C	-				

Pedestrian time settings

Time setting No.	Description	Limit	Pedestrian P1 (1)	P2 (2)	P3 (3)	P4 (4)	P5 (5)	P6 (6)	P7 (7)	P8 (8)
1	Delay	20	-	-	-					
2	Walk	40	6	6	6					
3	Clearance 1	40	10	10	20					
4	Clearance 2	10	2	2	2					
Auto switch			Off	Off	Off					
Pedestrian phases			C/A	A	B					

The entries in the timing card shown in Figure E 16 are discussed below. The following paragraph numbers match the time setting numbers in the timing card (and in the controller).

Phase time settings

1. **Red/yellow** – Not used (this controller feature is found in old sites only; practice has been discontinued and is not in accordance with current standards as seen in Part 10 of the Guide to Traffic Management) (Austroads 2019d).
2. **Late start** – The Phase A late start interval is used to hold the Phase C right turn red arrows at the start of Phase A in order to protect the pedestrian movement in front of the west approach.
3. **Minimum green** – Minimum green is G_{min} = 8 s for Phases A and B, and 6 s for Phase C.
4. **Increment** – This is not applicable since there are no passage detectors.
5. **Maximum initial green** – This is not applicable since there are no passage detectors (Appendix A).
6. **Maximum extension green** – These are calculated as the maximum green settings (reduced values) used in the SIDRA INTERSECTION analysis less the minimum green time, $G_{emax} = G_{max} - G_{min}$. Therefore, G_{emax} = 35 – 8 s = 27 s for Phases A and B, and G_{emax} = 14 – 6 = 8 s for Phase C are recorded in the timing card.

It is important to note that maximum green extension settings should be selected on the basis of analyses carried out for different flow periods (Appendix E.1) to satisfy requirements of different demand patterns and different demand flow levels in those periods.

7. **ECO (early cut off) green** – Not applicable since there are no staged terminations of movements.
8. **Yellow** – The values shown are based on the calculations given in Appendix E.3.1 (point 4) and Appendix E.4.1.
9. **All red** – The values shown are based on the calculations given in Appendix E.3.1 (point 4) and Appendix E.4.1.
10. **Special all red** – There are no special all red features.
11. **Gap 1** – This is the first gap setting for each phase. In Figure E 15, these are A, B1 and C-A1 detectors. The gap setting is e_s = 2.5 s for A and B1 detectors, and e_s = 2.0 s for the C-A1 detector.
12. **Gap 2** – This is the second gap setting for each phase. In Figure E 15, these are B2 and C-A2 detectors. The gap setting is e_s = 2.5 s for these detectors.

13,14 **Gap 3 and Gap 4** – These are not applicable since there are only two approach timers per phase (Figure E 15).

15–22 **Headway and waste** – Similar to the GAP time settings, headway and waste time settings are required for the first and second approach timers only.

Headway settings are 0.7 s for A, B1, B2 and C-A2 detectors, and 0.6 s for C-A1 detector (right turn movement).

Waste settings are usually determined as 10% of maximum green values, implying 3.5 s for Phases A and B, and 1.4 s for Phase C. However, these are less than the minimum values (Table G 1). Therefore, waste settings are 4.0 s for A, B1, B2 and C-A2 detectors, and 2.0 s for the C-A1 detector.

Special all red sequences

This is not applicable.

Prohibited sequences

Transition from Phase A to Phase C (due to skipping of Phase B) is prohibited so that both approaches of Main Road display yellow signals simultaneously to avoid a possible filter right turn conflict problem for the south approach of Main Road (Section 6.5.3).

Pedestrian time settings

1. **Delay** – Pedestrian delay setting is not used.
2. **Walk** – Walk time is 6 s for each pedestrian movement.
3. **Clearance 1** – Clearance 1 time (Figure G 2) is 10 s for P1 and P2, and 20 s for P3. These are based on the use of clearance distances of 14 m for P1 and P2, and 26 m for P3 (Section E.3.1).
4. **Clearance 2** – Clearance 2 time is 2 s for all pedestrian movements (2 s overlap with yellow time of the terminating intergreen, i.e. with Phase A intergreen for P1 and P2, with Phase B intergreen for P3).

Auto switch

This is not applicable since actuated pedestrian movements are used (this is used for introducing the pedestrian feature automatically with the associated phase).

Pedestrian phases

This indicates the phase(s) associated with each pedestrian movement.

Other time settings

Further time settings not shown in Figure E 16 are recorded on the timing card. These include special movement time settings, presence time settings, signal coordination features, and so on.

In this example, there are no special movements, and the only presence-timed detector is the 11 C-A1 detector (11 m long), where a presence time of 2 s is appropriate.

A-phase operates as the ‘recall’ phase to facilitate signal coordination along the north-south approach.

Appendix F Electrical Design of Traffic Signals

F.1 General

Electrical design is required for power and lighting circuits for the interconnection of signal components including controllers, lanterns, detectors and push-buttons. Cabling and wiring involved may provide one or more of the following:

- 240V 50 Hz circuits for lamps and post-mounted detectors
- extra low voltage 50 Hz circuits for pedestrian push-button demand indicators
- circuits for vehicle detector outputs
- digital data links associated with coordinated signal systems where dedicated cables or those leased from telecommunication authorities may be used.

The design function will need to provide details of duct sizes and access pits. Cable connection charts are required to identify each core of each cable, its function, connection details and cable routing. Such a chart is an essential document for installation and subsequent maintenance.

Adaptive engineering is required to enable the operation and maintenance of isolated or coordinated signal systems (Section 6.7).

F.2 Installation

All cable systems should be installed to the requirements of the local electricity authority and the requirements of AS/NZS 3000. This provides safety for both electrical workers and the general public. In this regard specific attention must be given to:

- adequate buried depth of cable
- earthing of signal hardware and equipment for electrical safety
- adequate separation/isolation/insulation of 240V and other cabling
- jointing of cables, at terminal strips located on the top of signal posts, and in either junction boxes attached to, or within the cavity of joint use columns and mast arms
- duct and access pit sizes to facilitate installation of cable.

F.3 Cables

Cables manufactured to the requirements of AS/NZS 2276 are used. For reasons of aesthetics and operational benefits, cables are installed underground. Multicore cables have core insulation based on a four-colour system as follows:

- earth core: green/yellow
- neutral core: black
- elv return: grey
- other numbered cores: white.

Installation techniques will depend on local practice and policies. The ‘common bus’ system or the radial routing system are two techniques used.

It should be noted that the conductor sizes of multicore cables are defined by AS/NZS 2276 Part 1. For long cable lengths or high electrical loading conditions, calculations of voltage drop and current carrying capacity may indicate that larger conductors are required. The number of circuits required will determine the number of cores required in each cable. Provision must be made for:

- one active cable core for each colour of each signal group
- one cable core for each pedestrian push-button demand circuit
- a number of spare cores (spare cores allow for modifications to the signal control mode without recabling; in the event of core damage, it may allow repair to be carried out without the need to replace the cable).

F.4 Vehicle Loop Detector Cables

For vehicle loop detector sensors either post-mounted or located in the controller housing, the feed to the loops should be by screened feeder cable manufactured to the requirements of AS/NZS 2276 Part 2.

The sensor to loop distance should be minimised since long lengths of feeder cable may have adverse effects on detector sensor operation. The loop cable should be manufactured to the requirements of AS/NZS 2276 Part 3.

F.5 Data Link Cables

Data link cables are either leased from telecommunication authorities or manufactured and installed to their requirements. The desired data transfer rate determines the cable types that are required. Aspects of Section F.2 are also pertinent.

F.6 Cable Connection Design

The cable connection design determines the size, length and routing of cables. The circuits connecting lanterns, push-buttons and wait indicators to the controller may be optimised, to produce the most economical solution.

The number of cores in the multicore cable is chosen to provide sufficient circuits for each colour of each signal group, push-button, and pedestrian wait indicator. The cores are connected from the post-mounted terminal block, on each post to the controller terminals.

The cable connection chart documents the cable connection design. Details of the connection of individual cable cores to the appropriate terminals in the controller and on each terminal block at each post are shown. A typical example is illustrated in Appendix E, Figure E 14.

Appendix G Signal Timings

G.1 Introduction

Allocation of appropriate green times to competing traffic movements at a signalised intersection requires considerations of safety, adequate capacity, efficient traffic operation (minimum delay, queue length and stops) for the intersection as a whole, as well as equity in levels of service provided for different movements (major road versus minor road, and vehicles versus pedestrians), and priority to public transport vehicles.

Table 6.8 presents a summary of signal controller settings, their purposes and recommended values.

This appendix provides more detailed information, discussing general aspects of signal timing methods (Appendix G.2), actuated signal controller operation (Appendix G.3), and guidelines for determining appropriate values of controller settings (Appendices G.4 to G.6).

Certain timing constraints are imposed on signal operation for safety reasons. Safety requirements constrain the minimum green time, minimum red arrow display time, minimum pedestrian walk and clearance times, and intergreen time. Maximum tolerable delay needs to be considered due to its implications for safe operation of signals (Appendix G.2.2).

G.2 Signal Timing Methods

G.2.1 Green Times and Cycle Time

Signal timing methods are used to determine appropriate green times and cycle time. Although most modern signals operate in actuated control mode, historically, signal timing calculation methods for fixed-time signals have been applied to actuated signals as well, mainly to determine the maximum green time (Akçelik 1981, Miller 1968, Webster & Cobbe 1966). Such methods calculate an ‘optimum’ or ‘practical’ cycle time, and then calculate green times on the basis of equal degrees of saturation or specified practical degrees of saturation, i.e. maximum acceptable (target) demand flow to capacity ratios.

Signal timing methods that estimate green times directly using actuated controller parameters, and then calculate the resulting cycle time, have been developed more recently (Akçelik 1995a, 1995b, 1995c; Transportation Research Board 2000).

SCATS Master Isolated Control (Section 6.7) is basically an actuated control method, but differs from the traditional actuated controller operation in determining appropriate green times on a cycle-by-cycle basis (Akçelik et al. 1998). The traditional vehicle-actuated control uses maximum green settings, i.e. maximum cycle time is not a setting. SCATS Master Isolated Control determines green times using the equal degree of saturation principle subject to a specified maximum cycle time. These green times act effectively as maximum green times, and the actual green times differ from these values when the phase changes occur by ‘gapping out’ (Appendix G.4.4).

Determination of appropriate cycle time and green times for coordinated signals is discussed in Section 6.9.

G.2.2 Maximum Tolerable Delay

Drivers and pedestrians will tolerate only limited delay at traffic signals, particularly if a red display appears to be maintained needlessly. Because of the inherent bounds of human patience, drivers and pedestrians may disobey red displays if delays are abnormally long. Therefore, an upper time limit must be set to green time for any movement to ensure that motorists are not kept waiting for an ‘excessive’ period against a red signal (Appendix G.4.3). The waiting time for traffic facing a red display depends on:

- traffic flows on the subject approach as well as flows on other approaches
- green time (actuated controller) settings
- requirements of signal coordination on a conflicting phase.

The ‘excessive’ time is related to the level of traffic activity at the intersection. The behaviour of drivers is also related to feelings of perceived equity. In other words, drivers can be held against a red display in a minor side street for relatively long periods compared to the waiting time tolerated by drivers on a busy arterial road.

Subjective observations suggest that maximum waiting times (against a red display) range from 20 seconds under light traffic conditions to 120 seconds under heavy traffic conditions. These values relate to the maximum delay experienced by an individual vehicle (or pedestrian). Average delay estimated by analytical methods is for all vehicles (or pedestrians) delayed and undelayed, and therefore, is shorter than maximum delay. For example, the worst level of service has been defined on the basis of average delay being above 70 to 80 seconds (Roads and Traffic Authority NSW 1993, Transportation Research Board 2000).

Increased green time for a movement results in increased red times for competing movements, which will then require longer times. This leads to increased cycle time. Maximum green settings should be selected to avoid very long cycle times in order to ensure acceptable levels of service. The recommended maximum cycle time for a two-phase intersection is 100 to 120 seconds (subject to signal coordination considerations) and is 150 to 180 seconds for sites with complex phasing systems and high traffic demands.

G.3 Actuated Controller Operation

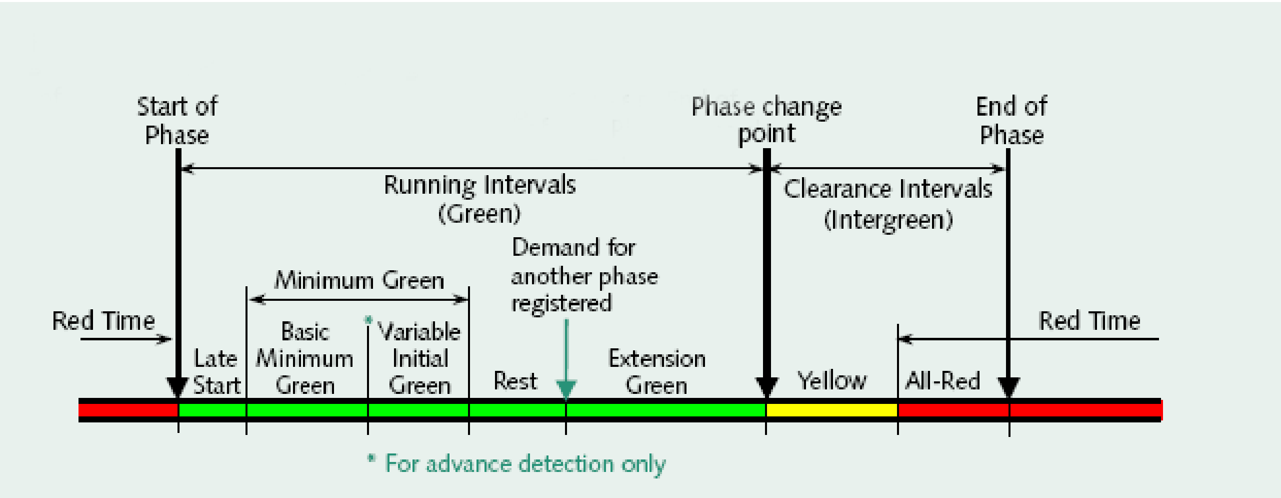
This section presents a description of how actuated signal controllers work. Although the discussion is relevant to actuated controllers generally, some specific aspects of controller operation are valid for the Australian controllers only (Akçelik 1995b, Roads and Traffic Authority NSW 2010c).

At vehicle-actuated signals, the green times, and hence the cycle time, are determined according to the vehicle demands registered by detectors (Section 6.8). This may be on the basis of phase control or group (movement) control. Phase sequence may be fixed or variable. A phase can be skipped when there is no demand for it. A phase (or signal group) consists of various intervals as discussed in Appendices G.3.1 and G.3.2.

G.3.1 Vehicle Phase Intervals

The vehicle phase (signal group) intervals are shown in Figure G 1. This does not include the early cut-off interval, which is discussed in Appendix G.4.5.

Figure G 1: Vehicle phase intervals



The running part of the phase corresponds to the period when the green signal is displayed. It is the period between the phase start and the phase change points. The clearance part of the phase corresponds to the period when the yellow and all-red signals are displayed. It is the period between the phase change point (the end of running intervals) and the beginning of the green display for the next phase (end of phase). Green time is the duration of running intervals, and the intergreen time is the duration of yellow time and all-red time.

Different signal indications can be displayed to different movements using the phase during the late start and early cut-off green intervals. The late start interval is used to delay the introduction of the green signal to some movements in the phase. The durations of these intervals are determined by the late start and early cut-off green settings (Appendices G.4.1 and G.4.5).

The two minimum green intervals used for safety reasons are the basic minimum green interval and variable initial green interval (Appendix A). With stop-line detectors, a basic minimum green setting determines the minimum green time allocated to a movement (Appendix A). The variable initial green interval is used with advanced detectors to provide additional minimum green time to discharge a queue of vehicles stored between the stop line and detectors during the red period. The duration of this interval varies in response to the number of actuations of the advance detectors and is determined according to the values of the vehicle increment and maximum initial green settings (Appendix A).

The controller cannot enter the extension green interval until a demand for another phase is registered. The rest interval is an untimed interval after the minimum green time expires, during which the controller rests until a demand for another phase is registered as shown in Figure G 1. The rest interval is skipped if a demand is registered for other phases before the end of the minimum green time.

The extension green interval is of variable length, and under isolated operation, its duration is determined by extension settings, namely the gap setting (Appendix G.4.4), headway and waste settings (Appendix G.4.7), and maximum extension green setting (Appendix G.4.3). In the case of parallel vehicle and pedestrian movements at intersections, the pedestrian walk and Clearance 1 intervals can hold the extension green interval (Appendices G.3.2 and G.5). The gap, headway and waste settings are used as 'space' (non-occupancy) time values as measured by presence detection.

The gap timing logic operates from the start of the green period to enable a green termination at the end of the minimum green period or the rest interval. It operates for the whole of the running part of the phase including the rest interval. The gap timer is loaded with the gap setting when a detector actuation occurs. With presence detection, the gap timer starts decrementing (from the initial value of the gap setting) when detector actuation ceases.

If the gap timer reaches zero before the next detector actuation, the timer is said to have timed out (or 'gapped out'). When this occurs during the extension green interval, the green period is terminated (subject to parallel pedestrian movement timing constraints). This point during the phase is called the phase change time. This type of extension green termination will be called a gap change. The phase change process starts with the yellow signal display unless there is an early cut-off green interval in which case the early cut-off yellow interval starts (Appendix G.4.5).

The current Australian control method employs headway and waste settings as additional extension settings. The headway-waste control method aims to terminate the extension green interval before gap change if the headways are too small for a gap change but too large for efficient traffic operation. The efficiency is measured by the difference of measured space times from the headway setting. The difference is called a waste increment.

A waste timer operates throughout the running part of the phase, but its operation is ignored until the start of the extension green interval (i.e. until the end of the minimum green period or until a demand for another phase is received, whichever comes later). At the start of the extension green interval, and at each detector actuation after that, the headway timer is loaded with the headway setting. When the detector actuation ceases (i.e. at the end of the occupancy time), the headway timer starts decrementing. If the headway timer reaches zero before another actuation occurs, the timer is said to have timed out. The headway timer may time out many times during a phase.

The value of the waste timer at the start of the extension green interval equals the waste setting. Whenever the headway timer is timed out, the waste timer starts decrementing until a new detector actuation occurs. The amount of decrement equals the waste increment. When the waste timer reaches zero, the waste timer is said to have timed out. When this occurs before a gap change, the phase will be terminated. This is referred to as a waste change.

In addition to a gap change or waste change, the phase can be terminated by a minimum change, or a maximum change.

The minimum change occurs when the phase ends at the end of the minimum green period when a demand for another phase has been received and the gap timer has timed out before the end of the minimum green period.

The maximum change occurs when a gap change or waste change has not occurred during the extension green interval and the total green extension time equals the maximum extension green setting.

In summary, subject to demand for another phase, the green period can be terminated by one of four methods:

- a minimum change
- a gap change
- a waste change
- a maximum change.

G.3.2 Pedestrian Intervals

At a signalised intersection, pedestrian movements can run concurrently with **parallel** vehicle movements, or run in an **exclusive** pedestrian phase. At mid-block signalised crossings, vehicle and pedestrian movements run in alternate phases.

Normally, pedestrian movements (phases) are introduced by push-button detection. For parallel crossings at intersections, pedestrian demand needs to be received before the relevant phase starts. Pedestrian movements (phases) can also be introduced automatically in areas where heavy pedestrian movements exist.

The pedestrian movement (phase) intervals, as well as their relationship with parallel vehicle movement intervals (applicable in the case of parallel vehicle and pedestrian movements at signalised intersections), are shown in Figure G 2. Pedestrian and vehicle phase intervals at a mid-block pelican crossing are shown in Figure G 3.

Pedestrian displays are Walk, flashing don't walk and steady don't walk. The flashing don't walk display corresponds to Clearance intervals 1 and 2. The Clearance 2 interval overlaps with part of the vehicle clearance interval.

The pedestrian delay interval provides a delay between the start of the phase and the start of the Walk display (Appendix G.5.4).

Figure G 2: Pedestrian movement (phase) intervals

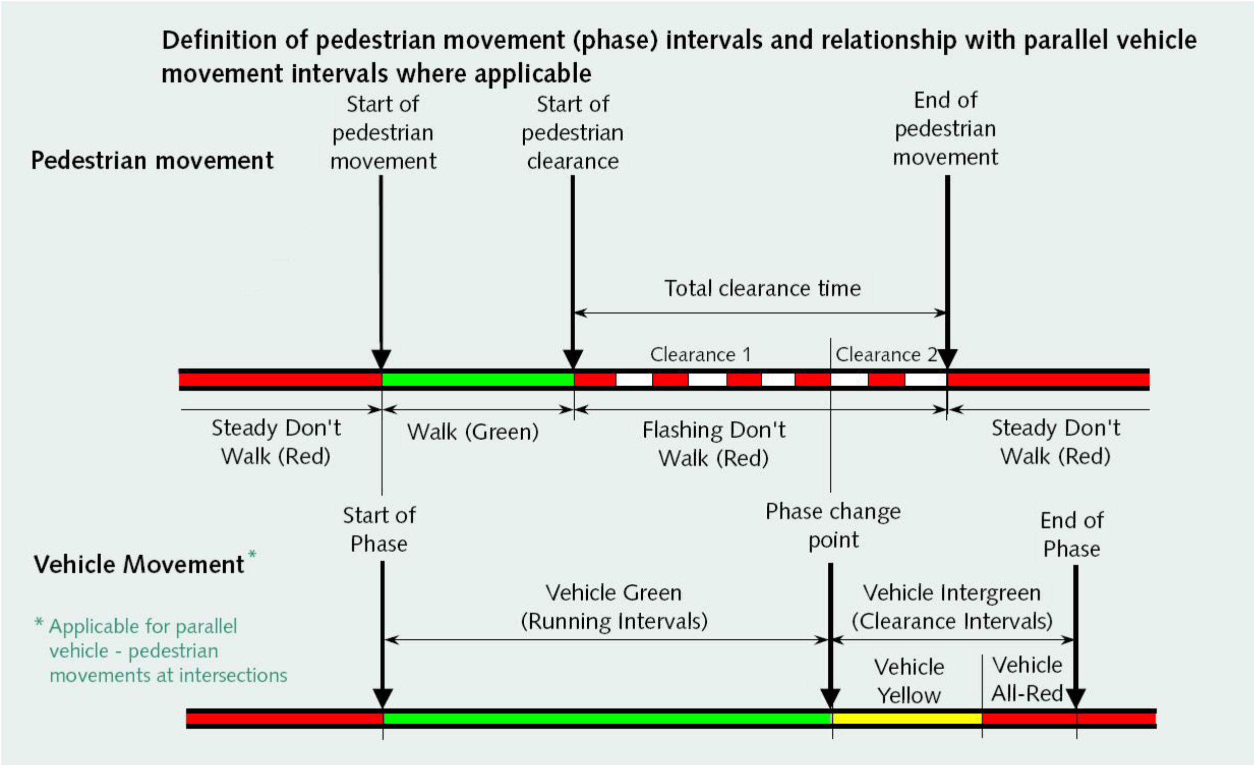
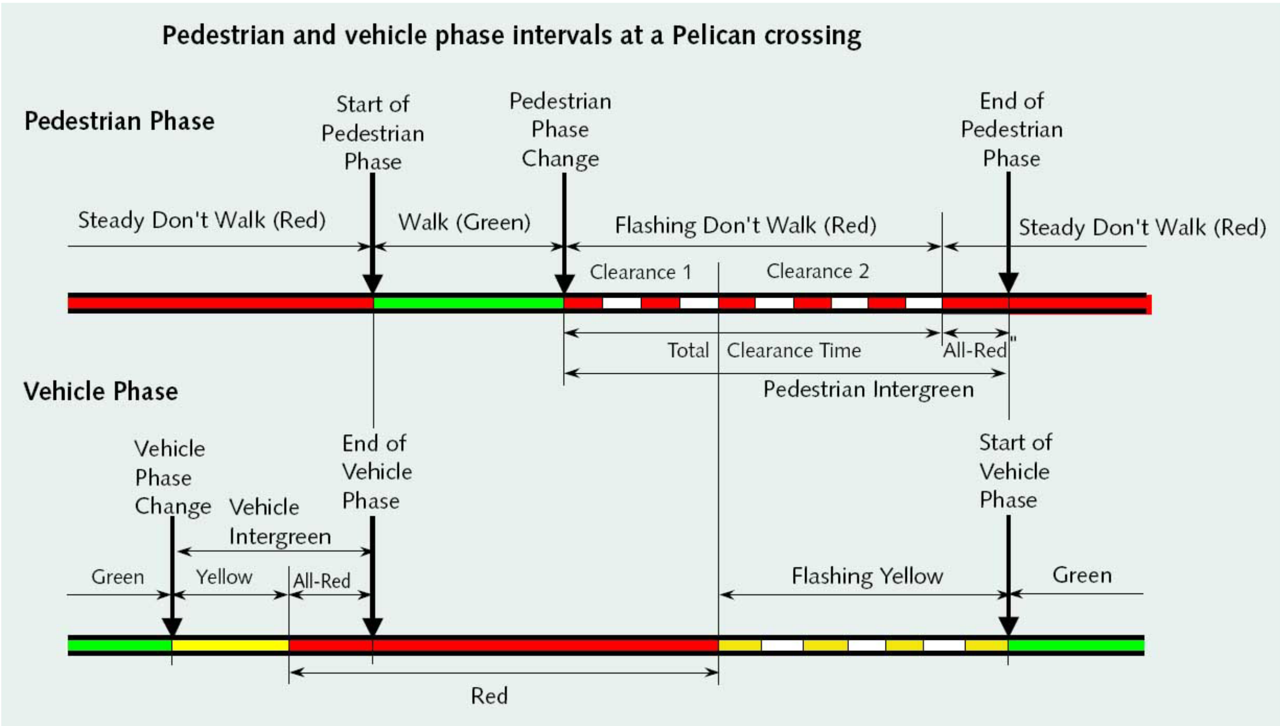


Figure G 3: Pedestrian and vehicle phase intervals – pelican crossing



For parallel crossings at signalised intersections, and subject to demand for another phase, a phase will start terminating at the end of the:

- pedestrian Clearance 1 interval if the vehicle running intervals expire before, or concurrently with it
- the vehicle running intervals if the pedestrian Clearance 1 interval expires before them.

For midblock signalised crossings and exclusive pedestrian phases at intersections, the pedestrian phase will start terminating at the end of the Clearance 1 interval regardless of a demand for another phase.

The minimum phase green time due to a pedestrian movement is determined as the sum of minimum walk time and Clearance 1 interval time. This will govern the minimum phase time when parallel pedestrian and vehicle movements operate concurrently and the minimum phase green time due to a pedestrian movement equals or exceeds the duration of vehicular running intervals for the phase.

Methods to determine pedestrian walk time and clearance time settings are described in Appendix G.5. Note that the relationship between the end of the pedestrian movement and end of phase (Figure G 2) varies between jurisdictions depending on the method used to calculate the total clearance time. Some jurisdictions use a walking speed of 1.2 m/s in the calculation of clearance time and terminate the Clearance 2 interval at the end of Vehicle All Red; others adopt a walking speed of 1.5 m/s provided that the flashing don't walk display does not overlap into the vehicle intergreen period. In practice, the timing outcomes are similar.

G.3.3 Actuated Controller Settings

Selecting appropriate values of controller settings for efficient operation of actuated signals for a given phasing system is not an easy task. The location, number and other characteristics of detectors affect the choice of actuated signal settings also.

For the purpose of determining the values of actuated controller settings, it is necessary to identify the proportion of flow in the critical lane. Critical lane is the lane that places the highest demand on green time in a given phase or signal group considering all movements in the phase or group. In terms of capacity analysis, this is the lane with the largest degree of saturation (demand flow rate to capacity ratio). Where capacities of all lanes are equal and all lanes are utilised equally, this is the lane with the highest demand flow rate. A simple manual method to determine the proportion of flow in the critical lane is given in Akçelik (1995b, Appendix B).

The methods recommended for determining actuated signal controller settings are described in Appendices G.4 to G.6.

Typical signal controller settings used in Australian practice are given in Table G 1.

Table G 1: Typical signal controller settings used with 4–4.5 m stop-line detectors in Australian practice

Setting	Vehicle settings (seconds)		Pedestrian settings (seconds)
	Through (and left turn) movements	Arrow -controlled right turn movements	
Late start	2–5	0–6	–
Minimum green	5–10	5–6	–
Maximum extension green	10–85	5–25	–
Gap	2.5–4.0	2.0–3.0	–
Headway	0.3–1.5	0.6–1.2	–
Waste	4–11	2–8	–
Early cut-off green	0–8	0	–
Yellow time	3.0–5.0	3.0–6.0	–
All-red time	1.0–3.0	1.0–3.0	–
Presence time	0–3	0–5	–
Walk time	–	–	5–16
Clearance time	–	–	6–20

Source: Akçelik (1995a and 1995b).

G.4 Vehicle Settings

Actuated controller settings for vehicle movements are described in the following sections which are presented in the order they appear in Table G 1.

G.4.1 Late Start Setting

The purpose of the late start setting is to allow the introduction of some signal groups to be delayed at the start of a phase for a pre-set time.

Examples of the use of this setting are:

- to delay the start of left turns: three to six seconds depending on intersection geometry
- to delay the start of a filtering right turn immediately following its control by a right turn green arrow display: five seconds.

G.4.2 Minimum Green Setting

The minimum duration of the green signal ('minimum green time') is determined considering the dynamic characteristics of the vehicles in the traffic stream. A starting delay is experienced when a signal changes from red to green. This delay includes allowance for the alertness of drivers (perception and reaction time), preparation of the vehicle (selecting gear, releasing hand-brake) and acceleration to the desired or possible speed.

There is also a safety element involved in determining the minimum green time, since drivers expect the signal to remain green for a 'reasonable' time, and a green interval which is unduly short leads to erratic behaviour and rear-end collisions.

Motorcycles and passenger cars have greater acceleration capabilities than trucks and, in the interests of safety, minimum green time should be related to the slowest vehicle likely to use the intersection within 95% probability (5th percentile speed).

Minimum green time comprises the basic minimum green setting (see below) plus a variable time determined by the increment and maximum variable initial green settings (see below).

The basic minimum green setting is the minimum time a green aspect can be displayed when stop-line detectors are used. When using only advance detectors, the minimum green time is increased above this value in order to allow for vehicles stored between the stop line and advance detector location. The increment and maximum variable initial green settings are used for this purpose. For stop-line detectors, the maximum variable initial green setting is zero.

A method for determining the maximum variable initial green and increment settings is given in Akçelik (1995b, Appendix B).

Basic minimum green setting

With stop-line detectors, the minimum green time is equal to the basic minimum green setting. A longer minimum green display is required when advance detectors only are used (see below).

A minimum green time is needed to ensure that the green signal (circle or arrow) is displayed for a safe minimum time, i.e. not less than 5 seconds. This is to provide enough time for a stationary vehicle at the stop line to begin moving and enter the intersection. At a particular site, there may be a need to increase the minimum green time to allow for heavy vehicles, a steep upgrade, pedestrians, or clearing of turning traffic. Typical minimum green settings used in practice with stop-line detectors are shown in Table G 1.

Increment and maximum variable initial green

The increment and maximum variable initial green settings are applicable when only advance detectors are used.

Each vehicle arriving against a red signal adds a small amount of time (equal to the increment setting) to the minimum green time. This provides sufficient green time to enable those vehicles stored between the detector and the stop line to clear the intersection. Typical increment settings are in the range 0.5 to 2.0 seconds depending on the number of approach lanes and the location of the advance detectors. Careful site observation is required under a range of conditions, especially where lane utilisation varies. It is recommended that an increase for upgrade and a decrease for downgrade be made at the rate of 0.1 second for each per cent of road grade.

The maximum variable initial green setting limits the additional minimum green time (variable initial green time) determined by increments. The value of this setting depends on the distance of advance detectors from the stop line. For example, if the distance is 50 m, then for an average spacing of 7 m per vehicle, seven vehicles will store between the detectors and the stop line in each lane. Using a start loss of two seconds for the first vehicle at the start of the green period, and assuming that a car leaves the queue every two seconds, the required setting is 2 + 7 x 2 = 16 seconds. If the basic minimum green setting is six seconds, then the required maximum variable initial green setting is 16 – 6 = 10 seconds.

Again careful site observation is required to ensure that there is sufficient variable initial green time so that vehicles queued beyond the detectors can move over them and thus extend the phase.

G.4.3 Maximum Extension Green Setting

The maximum extension green setting is used to control the maximum green time available to each phase or signal group when conflicting demands exist and when operating in the isolated mode. This setting determines the duration of the extension green interval (Figure G 1).

Maximum green time is the sum of minimum green time (Appendix A) and the maximum extension green setting. In some controllers, a maximum green setting equivalent to the maximum green time is used.

As seen in Table G 1, typical maximum extension green settings used in practice are 10 to 85 seconds for through movement phases and 5 to 25 seconds for arrow-controlled right turn phases.

The maximum green times should be determined with the objectives of ensuring equitable distribution of green time amongst competing signal groups (movements) and achieving optimum traffic performance (e.g. minimum delay, stops or queue length), considering different traffic demand periods. This is a key parameter for optimising the performance of actuated traffic signals.

When determining maximum green times, a balance needs to be achieved between:

- erring on the long side considering that the gap setting should reduce the green time if necessary
- large maximum green time values for individual phases (or signal groups) which can add up to unduly long cycle times resulting in intolerable delay (Appendix G.2.2).

The optimum values of maximum green times produced by an appropriate software package could be used as a guide to determining the maximum extension green settings with the above criteria in mind (maximum extension green setting = maximum green time – minimum green time).

Equation A1 provides a simple manual method for determining the maximum extension green setting (Akçelik 1995b, Appendix B):

$$G_{emax} = [y\ R_{max} / (x_p - y)] - G_{min} \qquad \text{A1}$$

where

G_{emax} = maximum extension green setting (s)

G_{min} = minimum green time (= basic minimum green setting with stop-line detectors) (s)

y = flow ratio (demand flow rate/saturation flow rate) for the critical lane

R_{max} = maximum red time that is acceptable to drivers (e.g. 60 seconds)

x_p = practical degree of saturation (maximum value acceptable at high demand conditions), e.g. x_p = 0.95

G.4.4 Gap Setting

The gap setting is used to set the maximum allowable time between successive detector actuations before the movement terminates due to large gaps between vehicles. If the gap setting is too short, the phase may terminate before a platoon of vehicles is passed, and if it is too long, the phase will extend unduly.

Microprocessor-based controllers provide for at least two and up to eight gap timers so that different approach characteristics such as grade and turning radius, can be catered for.

The gap setting is determined as a space time value measured between consecutive vehicles by the detector, i.e. as the time when the detector is not occupied.

Table G 1 indicates that typical gap settings used in Australian practice are in the range 2.5 to 4.0 seconds for through (and left turn) movements, and 2.0 to 3.0 seconds for arrow-controlled right turn movements.

A method to determine gap settings is discussed in Akçelik, Besley and Roper (1999).

The ‘headway setting’ and ‘waste setting’ used in association with the gap setting are discussed in Appendix G.4.7. Analytical and simulation studies indicated that these settings do not influence the green duration as much as the maximum extension green and gap settings (e.g. Akçelik 1995b).

G.4.5 Early Cut-off Green and Early Cut-off Yellow Settings

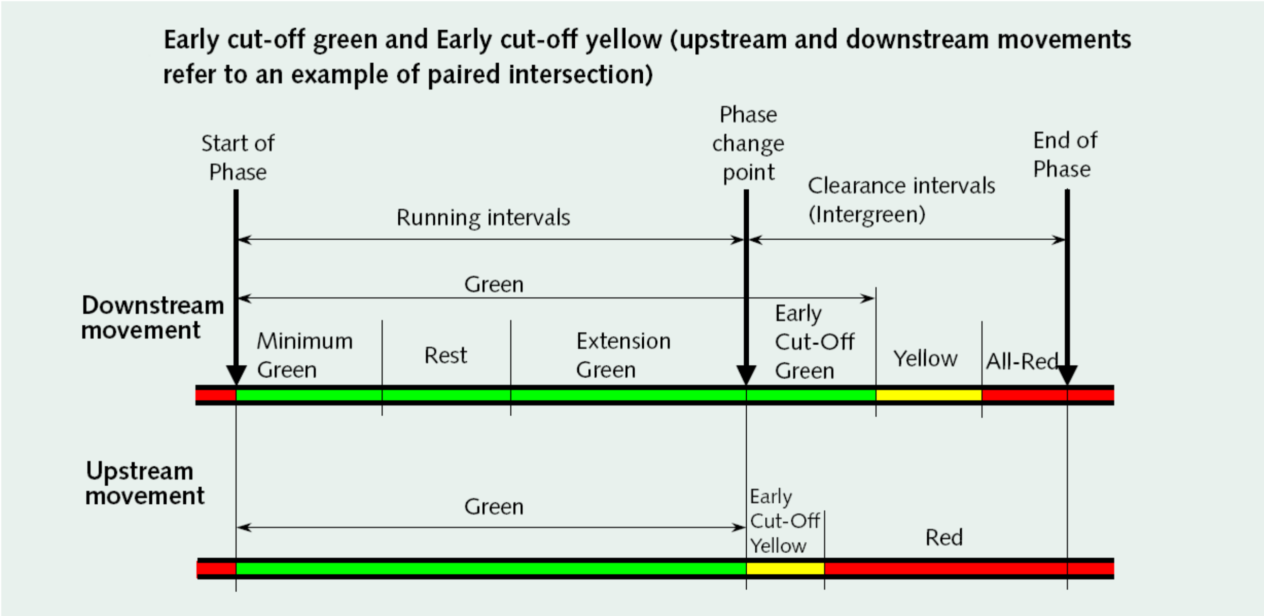
The early cut-off green interval allows the termination of some signal groups earlier than others. This arrangement is shown in Figure G 4. For example, at paired intersections, the upstream signals may be terminated earlier than the downstream signals in order to minimise queuing on internal approaches. It is effectively an internal offset.

The early cut-off green setting depends on intersection geometry, but normally should not be less than three seconds.

The early cut-off yellow interval is an auxiliary phase interval used to provide a yellow display for any signal groups that are terminated at the beginning of the early cut-off green interval. It is equal to the yellow setting for the phase within which the early cut-off operates.

The early cut-off green interval follows the phase change point, and is considered to be part of the clearance interval (intergreen time).

Figure G 4: Early cut-off green and early cut-off yellow



G.4.6 Vehicle Clearance Settings

The intergreen period as a vehicle change and clearance interval involves two intervals:

- a yellow interval to warn approaching drivers that the phase is terminating
- an all-red interval to enable vehicles within the intersection to clear the controlled area.

There are a large number of publications on determining appropriate values of yellow time and all-red time (e.g. Hulscher 1980, 1984; Institute of Transportation Engineers 1994, McGee et al. 2012). It is recommended that the yellow time and the all-red time be set as detailed below.

Yellow time

The purpose of the yellow interval is to provide sufficient warning of the termination of the phase. A driver must stop for a yellow display provided it can be done safely.

Table G 1 indicates that typical yellow times used in practice are in the range 3.0 to 6.0 seconds.

Traffic regulations prohibit the entry of vehicles into a controlled area when a red signal is displayed. The yellow signal is used to allow for the fact that a traffic stream cannot be stopped abruptly at the end of the green interval. The stopping performance of drivers is related to reaction time, braking characteristics of the vehicle, distance from the stop line, road gradient, approach speed, discomfort tolerance and behaviour of following traffic. Since accident risk is highest during the transition from green to one movement (phase) to green to another movement (phase), the timing of this change interval is very important.

The braking capability of modern vehicles is high, and in practice the discomfort incurred by rapid deceleration is the main constraint in controlled stops. Another important consideration is the perceived danger of a rear-end collision with a following vehicle (particularly a heavy vehicle), which may not be prepared for the sudden deceleration. These considerations are so important to many drivers that their first inclination is to attempt to cross the intersection during the yellow period.

The yellow interval should only be long enough to enable traffic to comply with regulatory requirements. If the yellow interval is too short, vehicles within a certain distance from the stop line will be unable (or unwilling) to stop before the red signal appears, and if the yellow time is too long, motorists will tend to abuse the signal. As Gazis et al. (1960) have shown, an inappropriate choice of yellow time can place an approaching driver, at the onset of the yellow signal, in the predicament of being too close to the intersection to stop safely and comfortably, and yet be too far from it to clear the conflict area or even reach the stop line before the red signal appears. This phenomenon is related to approach speed and is generally analysed in terms of the 'dilemma zone'.

The yellow time should be just sufficient to enable a driver approaching at the design speed who is unable to stop in advance at the stop line to cross the stop line before the red signal appears. In other words, the duration of the yellow signal is dictated by the needs of the driver who requires the maximum deceleration acceptable to the majority of the population (say 85%). This criterion ensures that drivers travelling at or below the speed limit will not be caught in the 'dilemma zone' and that the yellow interval is no longer than necessary. Thus, the yellow time should be equal to the sum of the driver's reaction time and the time to reach the stop line at the design speed, v_D.

This can be mathematically expressed as (Equation A2):

$$t_y = t_r + 0.5\ (v_D / 3.6) /(a_d + 9.8\ G) \text{ subject to } t_y \geq 3.0 \qquad \text{A2}$$

where

t_y = yellow time (s)

t_r = reaction time (s), commonly taken in these circumstances as being between 1.0 s and 1.5 s

v_D = design speed (km/h)

a_d = the deceleration acceptable to the majority of drivers (m/s^2), commonly taken as 3.0 m/s^2, but in the case of heavy vehicles a lesser value may be appropriate

G = average approach grade over the stopping distance (per cent grade divided by 100; negative value for downhill grade and positive value for uphill grade, e.g. –0.05 for 5% downhill grade)

Recent studies (McGee et al. 2012, Moriarty et al. 2012) confirm that driver reaction time for traffic signal timing calculations lies in the range of 1.0 to 1.5 seconds. This encompasses the range from mean to 85th percentile values observed in practice. It is therefore appropriate to adopt a value of 1.0 seconds as a minimum value for calculation of yellow times.

The yellow time values derived from Equation A2 using t_r =1.0 seconds and a_d = 3.0 m/s^2, for design speeds of v_D = 40, 50, 60, 70, 80 and 90 km/h, rounded as indicated in the following, are given in Table G 2. By applying the minimum value for t_r, these values represent the minimum yellow times that will allow a driver approaching at the design speed to stop in advance of the stop line before the red signal appears. This assumes that a deceleration rate of 3.0 m/s^2 is representative of the majority of drivers.

The calculated values for yellow time from Equation A2 are rounded up to the nearest 0.5 second for practical reasons, and to ensure from a safety perspective that the implied values for driver reaction time are not less than 1.0 second.

The effect of approach grade on the yellow times is also illustrated in Table G 2, for ranges of grade up to 15%, downhill and uphill. The values are determined from Equation A2 and rounded as indicated above, subject also to adoption of an absolute minimum value of 3.0 seconds. Where a grade correction is considered appropriate, Table G 2 has been prepopulated to assist in implementation.

The yellow times for an intersection on a grade must be the same for opposite traffic streams.

Table G 2: Yellow time values

Approach grade	v_D = 40 km/h	v_D = 50 km/h	v_D = 60 km/h	v_D = 70 km/h	v_D = 80 km/h	v_D = 90 km/h
11% to 15% downhill	5.0	6.0	6.5	7.5	8.5	9.5
6% to 10% downhill	4.0	4.5	5.5	6.0	6.5	7.5
5% downhill	3.5	4.0	4.5	5.0	5.5	6.0
Level	3.0	3.5	4.0	4.5	5.0	5.5
5% uphill	3.0	3.0	3.5	4.0	4.5	5.0
6% to 10% uphill	3.0	3.0	3.5	4.0	4.5	4.5
11% to 15% uphill	3.0	3.0	3.5	3.5	4.0	4.5

Note: Determined using a_d = 3.0 m/s^2 and t_r = 1.0 s.

All-red time

An all-red interval is used between the end of the yellow interval of a phase or signal group and the commencement of the green on the next phase or signal group. The purpose of the all-red interval is to provide a safe clearance for vehicles that cross the stop line towards the end of the yellow interval since they may be in danger of collision with vehicles or pedestrians released in the following phase or signal group.

As seen in Table G 1, typical all-red times used in practice are in the range 1.0 to 3.0 seconds.

The timing of an all-red interval should take account of the speed of vehicles crossing the stop line at the end of the yellow interval, the distance to the furthest potential point of conflict with vehicle and pedestrian traffic of the next phase, the length of the clearing vehicle and the time for starting traffic to reach the furthest point of potential conflict with vehicles or pedestrians. A detailed method to take these factors into account was described by Hulscher (1980). Equation A3 is recommended for determining the all-red time:

$$t_{ar} = 3.6\ L_c\ /\ v_D \text{ subject to } t_{ar} \geq 1.0 \qquad \text{A3}$$

where

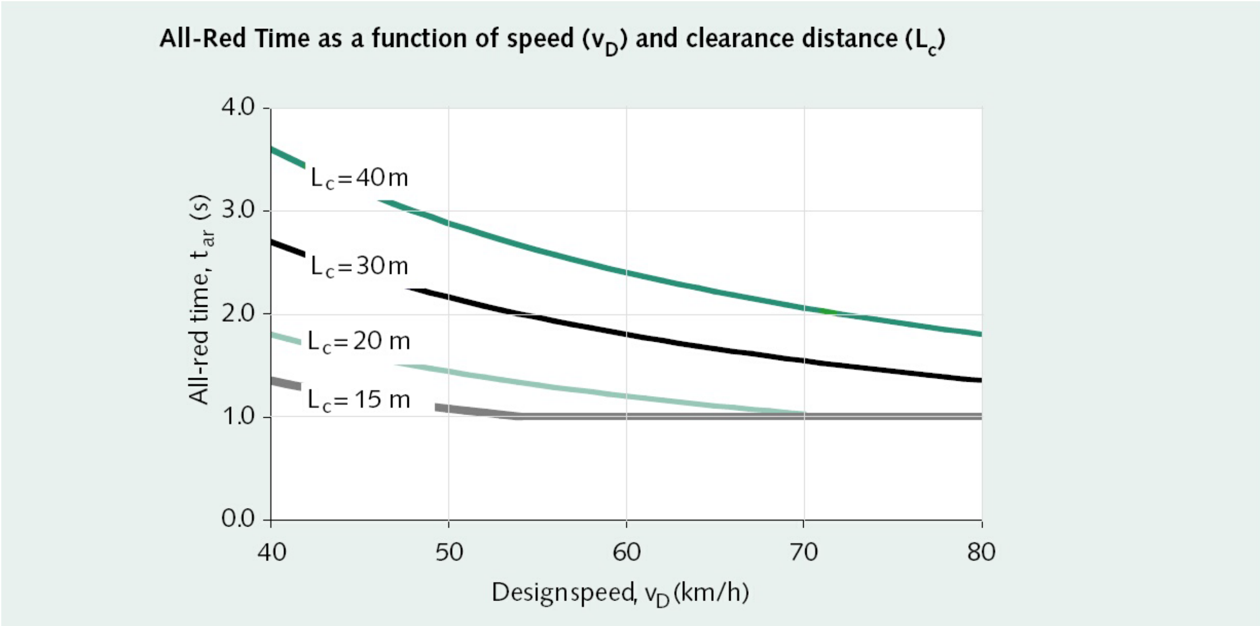
t_{ar} = all-red time (s)

L_c = clearance distance between the stop line and furthest point of potential conflict with vehicles or pedestrians of the next phase (m)

v_D = design speed (km/h)

The all-red time values calculated as a function of speed for various clearance distances are shown in Figure G 5.

Figure G 5: All-red time as a function of speed and clearance distance



While there may be isolated instances when longer all-red times are justified to meet unusual traffic situations, additional all-red time must not be provided to clear any vehicles waiting to make a right-hand turn. Excessive all-red times are likely to give rise to 'running the red' behaviour, particularly if yellow times are too short.

A special all-red setting for a phase is used for phase transitions that require significantly longer or shorter all-red values (e.g. due to phase skipping) compared with the all-red setting for normal phase transition.

Advance warning signal settings

As discussed in Part 10 of the Guide to Traffic Management (Austroads 2019d), advance warning signals are an active warning device consisting of a warning sign with alternating flashing yellow lights.

The time settings of the separate signal group comprising the advance warning signals depends on the reason behind the installation of the signal, as described below:

- Where the advance signal is installed on a road with a high proportion of heavy or long combination vehicles, and a high risk of frequent infringement of signals and a high risk of rear-end and cross accidents due to the inability to stop in time for the red display, e.g. due to high approach speeds or significant downhill grade:
  - the flashing yellow lights are started a fixed time in advance of the yellow interval when the main through-traffic phase is terminating at the intersection, using the early cut-off period timer (Appendix G.4.5)
  - the flashing lights may be terminated at the start of the red display for the main through traffic phase
  - in some jurisdictions, the flashing lights are terminated at the start of the next green display, which provides an additional level of safety.
- Where a traffic signal installation is obscured from the view of approaching traffic such that there is a high risk of collision with the rear end of traffic queued at the signals:
  - the yellow lights will need to flash beyond the start of the green display when the sight distance to the back of the queue for the through movement is a problem
  - the back of the queue will not begin to move until some seconds after the green signal is displayed
  - this time can be calculated as the 95th percentile queue value (in vehicles) times the queue departure response time. Akçelik et al. (1999) reported a typical queue departure response time of 1.15 seconds per vehicle in the queue observed at intersections in Melbourne and Sydney.

G.4.7 Other Vehicle Settings

Presence setting

This is used to set the time for which a detector must be occupied before a demand is recorded, or to prevent a demand being recorded unnecessarily.

Typical values of the presence setting used in practice are in the range zero to five seconds. Examples of the use of this setting are:

- shared lane detector for lagging right turn phasing: two to five seconds
- left turn detector on overlapped movement: three seconds
- left turn on red lane detector: zero.

Headway and waste settings

The purpose of 'headway' (space time) settings is to set the desirable space time between successive detector actuations for efficient traffic flow. It is used in association with the waste setting.

In general traffic engineering usage, the term 'headway' means the time between passage of the front ends of two successive vehicles at an observation point, e.g. at the leading edge of the detector. The term 'headway setting' is thus a misnomer as it is a 'space time' value, not a true 'headway' value.

As seen in Table G 1, typical 'headway' settings used in practice are 0.3 to 1.5 seconds for through movements and 0.6 to 1.2 seconds for arrow-controlled right turn movements. The 'headway' setting can be related to the SCATS parameter 'space time at maximum flow'. The values of this parameter were found to be 0.85 to 1.02 seconds for through movements and around 0.61 to 0.74 seconds for arrow-controlled right turn movements (Akçelik et al. 1999).

The waste is the sum of the excess of the actual space time over the 'headway' setting. The waste setting is used to set the value of this sum at which the phase is terminated (Appendix G.3.1). However, research has indicated that, with efficient gap settings as discussed in Appendix G.4.4, the phase (or signal group) is more likely to 'gap out' before a phase change due to the waste setting.

Where employed, the waste setting may be determined as 10–20% of maximum green time (minimum green time plus maximum extension green setting) subject to a minimum value of 4 seconds and a maximum value of about 12 seconds.

Table G 1 indicates that typical waste settings used in practice are 4 to 11 seconds for through movements and 2 to 8 seconds for arrow-controlled right turn movements.

Minimum red arrow time

The minimum duration of a red arrow signal display is governed principally by driver reaction/perception characteristics. It is recommended that, as a safety constraint, a minimum value of three seconds be used.

G.5 Pedestrian Settings

Actuated controller settings for pedestrian movements are described in the following sections (Figure G 2 and Figure G 3).

G.5.1 Pedestrian Walk Time

The purpose of the walk time setting is to give pedestrians sufficient time to begin their crossing. This setting determines the duration of the green Walk display. Its value depends on the amount and type of pedestrians using the crossing. Table G 1 that typical pedestrian walk times used in practice are in the range 5 to 16 seconds.

Pedestrian walk times can be determined as follows:

- Use a minimum value of five seconds. However, where the signalised crossing is on a very narrow carriageway (such as a slip lane), a minimum of four seconds is permissible.
- Add two seconds for each additional rank of pedestrians waiting (optional).
- Allow more time for:
  - schools
  - railway stations
  - elderly, children, and people with disabilities
  - crossing of wide roads in one movement (i.e. beyond medians).

When crossing a wide road with a median in one movement, the walk time may be calculated from Equation A4:

$$t_{pw} = L_{pw} / v_{pw} \text{ subject to } t_{pw} \geq 5 \qquad \text{A4}$$

where

t_{pw} = pedestrian walk time (s)

L_{pw} = pedestrian walking distance (m), determined as the larger of the 'first carriageway width plus median width' measured in each direction, and

v_{pw} = pedestrian walking speed (m/s)

When walk time is determined using Equation A4, the calculation of clearance distance is based on the larger of the two carriageway widths, i.e. excluding the median width, as discussed in Appendix G.5.2.

For pedestrian walking speed in Equation A4, use the clearance speed, vpw = vpc (Appendix G.5.2).

Where pedestrian demands are high (such as may occur in shopping areas), signal timings for the intersection may be biased to favour pedestrians. The pedestrian walk time can be increased in line with the green display for the parallel vehicle movements.

G.5.2 Minimum Green Setting

The minimum duration of the green signal ('minimum green time') is determined considering the dynamic characteristics of the vehicles in the traffic stream. A starting delay is experienced when a signal changes from red to green. This delay includes allowance for the alertness of drivers (perception and reaction time), preparation of the vehicle (selecting gear, releasing hand-brake) and acceleration to the desired or possible speed.

There is also a safety element involved in determining the minimum green time, since drivers expect the signal to remain green for a 'reasonable' time, and a green interval which is unduly short leads to erratic behaviour and rear-end collisions.

Motorcycles and passenger cars have greater acceleration capabilities than trucks and, in the interests of safety, minimum green time should be related to the slowest vehicle likely to use the intersection within 95% probability (5th percentile speed).

Minimum green time comprises the basic minimum green setting (see below) plus a variable time determined by the increment and maximum variable initial green settings (see below).

The basic minimum green setting is the minimum time a green aspect can be displayed when stop-line detectors are used. When using only advance detectors, the minimum green time is increased above this value in order to allow for vehicles stored between the stop line and advance detector location. The increment and maximum variable initial green settings are used for this purpose. For stop-line detectors, the maximum variable initial green setting is zero.

A method for determining the maximum variable initial green and increment settings is given in Akçelik (1995b, Appendix B).

Basic minimum green setting

With stop-line detectors, the minimum green time is equal to the basic minimum green setting. A longer minimum green display is required when advance detectors only are used (see below).

A minimum green time is needed to ensure that the green signal (circle or arrow) is displayed for a safe minimum time, i.e. not less than five seconds. This is to provide enough time for a stationary vehicle at the stop line to begin moving and enter the intersection. At a particular site, there may be a need to increase the minimum green time to allow for heavy vehicles, a steep upgrade, pedestrians, or clearing of turning traffic. Typical minimum green settings used in practice with stop-line detectors are shown in Table G 1.

Increment and maximum variable initial green

The increment and maximum variable initial green settings are applicable when only advance detectors are used.

Each vehicle arriving against a red signal adds a small amount of time (equal to the increment setting) to the minimum green time. This provides sufficient green time to enable those vehicles stored between the detector and the stop line to clear the intersection. Typical increment settings are in the range 0.5 to 2.0 seconds depending on the number of approach lanes and the location of the advance detectors. Careful site observation is required under a range of conditions, especially where lane utilisation varies. It is recommended that an increase for upgrade and a decrease for downgrade be made at the rate of 0.1 second for each per cent of road grade.

The maximum variable initial green setting limits the additional minimum green time (variable initial green time) determined by increments. The value of this setting depends on the distance of advance detectors from the stop line. For example, if the distance is 50 m, then for an average spacing of 7 m per vehicle, seven vehicles will store between the detectors and the stop line in each lane. Using a start loss of two seconds for the first vehicle at the start of the green period, and assuming that a car leaves the queue every two seconds, the required setting is 2 + 7 x 2 = 16 seconds. If the basic minimum green setting is six seconds, then the required maximum variable initial green setting is 16 – 6 = 10 seconds.

Again careful site observation is required to ensure that there is sufficient variable initial green time so that vehicles queued beyond the detectors can move over them and thus extend the phase.

G.5.3 Pedestrian Clearance Time

The purpose of the pedestrian clearance time is to allow pedestrians, who have stepped off the kerb at the commencement of the pedestrian clearance interval, to complete their crossing with safety. It comprises Clearance 1 and Clearance 2 intervals as seen in Figure G 2 and Figure G 3.

The pedestrian clearance interval is implemented using a flashing don't walk display. However, during the intergreen interval terminating the phase, the flashing don't walk or steady don't walk displays can be used as part of the clearance period (except, in some jurisdictions, only the steady don't walk may be displayed when filter right turns are allowed with parallel pedestrian movements).

As seen in Table G 1, typical pedestrian clearance times used in practice are in the range 6 to 20 seconds. The pedestrian clearance time should be determined using Equation A5 and Equation A6:

1. Calculate the total clearance time (in seconds) from:

$$t_{pc} = L_{pc} / v_{pc} \qquad \text{subject to } t_{pc} \geq 5 \qquad \text{A5}$$

where

t_{pc} = total pedestrian clearance time (s)

L_{pc} = pedestrian clearance distance (m)

v_{pc} = pedestrian walking speed (m/s)

2. Determine the durations of the Clearance 1 and Clearance 2 intervals (t_{c1} and t_{c2}) from:

$$t_{c2} = I \qquad \text{A6}$$

$$t_{c1} = t_{pc} - I$$

where

I = intergreen time (s) (Appendix G.4.6)

t_{pc} = total clearance time (s) from Equation A5

The pedestrian clearance distance in Equation A5 is based on the length of the marked crossing between kerb lines. Where the sides of the crossing are of unequal length, the length of the longest side is used.

If a median exists, its width is included in the clearance distance when crossing both carriageways in one movement, i.e. the pedestrian clearance distance includes both carriageway widths as well as the median width. However, if the walk time is calculated using Equation A4 for the case when crossing a wide road with a median in one movement, the clearance distance in Equation A5 should be based on the larger of the two carriageway widths (i.e. excluding the median width).

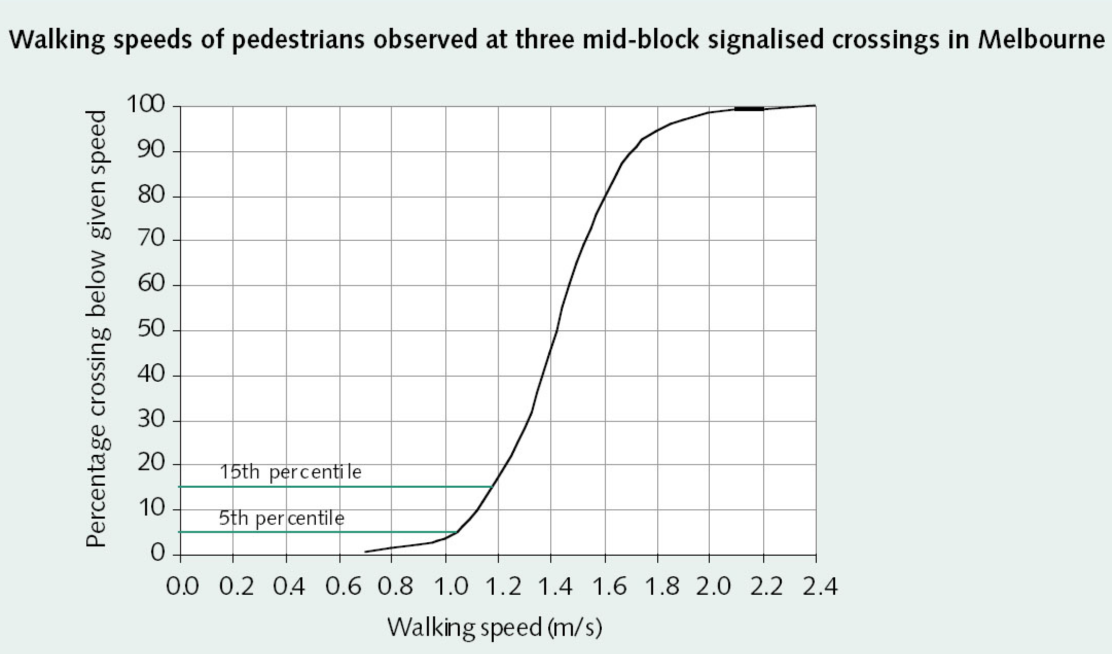
Where a median is wide enough to store pedestrians, a staged signalised crossing can be used. In this case, the crossings are treated separately, and the width of appropriate carriageway is used as the clearance distance for each crossing.

Where an exclusive pedestrian phase is provided at an intersection, the shortest distance between diagonally opposite corner kerb radii for the longest crossing is used as the clearance distance.

The pedestrian walking speed for determining total clearance time is usually 1.2 m/s. In some jurisdictions a walking speed of 1.5 m/s is adopted for the calculation of the Clearance 1 time provided that the flashing don't walk display does not overlap into the vehicle intergreen period. A clearance speed of v_{pc} = 1.0 m/s may be appropriate for sites with higher populations of slower pedestrians.

Figure G 6 shows the distribution of walking speeds at mid-block signalised crossings in Melbourne (Akcelik & Associates 2001). This indicates that the recommended clearance speeds of 1.0 and 1.2 m/s correspond to 5th and 15th percentile speeds, respectively, i.e. approximately 5% of pedestrians were observed to cross with speeds below 1.0 m/s, and 15% were observed to cross with speeds below 1.2 m/s.

Figure G 6: Walking speeds of pedestrians



G.5.4 Pedestrian Delay Setting

The pedestrian delay setting is used to provide a delay between the start of a phase (i.e. the start of green for the parallel vehicle movement) and the start of the Walk display. This helps to form pedestrian platoons and thus avoid unnecessary introduction of the pedestrian movements.

Where used a typical pedestrian delay setting is 5 to 10 seconds, applicable to both mid-block pedestrian controllers and intersection controllers with a completely independent pedestrian feature.

G.6 Cyclist Settings

Two-aspect bicycle signal faces used at mid-block signalised crossings or intersection signalised crossings are connected to the same signal group in the controller that drives the two-aspect pedestrian signal faces. In this case, the pedestrian ‘walk’ and ‘clearance’ times apply to the bicycles as well.

Three-aspect bicycle signal faces can also be used at signalised intersections. In this case:

- For bicycle movements parallel with a main road and crossing narrow minor roads, the bicycle signal faces are connected to the adjacent vehicle signal group, and introduced with the green display for vehicles and terminated with the vehicle movement.
- For bicycle movements across a main road, and for those parallel with a main road and crossing wide minor roads, the bicycle signal faces are driven by a separate signal group with green, yellow and red times that reflect a bicycle speed of 20 km/h.

The following measures can be adopted in order to allow for slower speeds of cyclists compared with vehicle speeds:

- Adjusting the yellow time for the bicycle movement to warn cyclists to stop before other traffic in the same phase, i.e. increase the intergreen time only for the cyclists (effectively providing an early cut-off). Since this reduces the bicycle green time, it should be ensured that the combined green plus intergreen time is sufficient for a cyclist accelerating from rest at the stop line to clear the controlled area.
- Allowing the cyclists to move off before the vehicle traffic (late start). This is appropriate where the bicycle lane does not continue through the intersection and bicycles have to merge with other traffic.

Appendix H Pedestrian Push-button Location

H.1 General

Pedestrian push-buttons are normally mounted on traffic signal posts or mast arms. The push-buttons should be located at each end of the signalised crossing and at each pedestrian refuge. Consideration should be given to provision of a push-button on any median island signal post.

Typical locations of push-buttons are illustrated in Figure H 1. They should be located so as to be clearly visible to approaching pedestrians and should not be obstructed by other road or footpath furniture.

H.2 Height

The push-button should be mounted at a height of 1 m ± 0.1 m from the ground.

H.3 Orientation

Where provided, pedestrian push-buttons should be orientated as follows (Figure H 1):

1. Orientated at the kerbside so that they are parallel to the crossing and facing towards pedestrians about to use the crossing, in accordance to AS 1742.14.
2. In narrow medians, one push-button may be mounted on the median post with its face parallel to the signalised crossing.

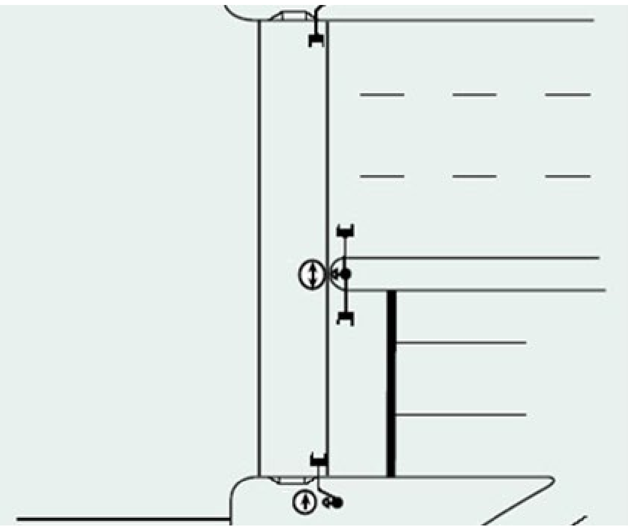
H.4 Arrow Legends

An arrow legend should be included on the face of the push-button assembly. This is used to give guidance to people with visual disabilities. The arrow should point towards the associated crosswalk lines as shown in Figure H 1, namely:

- The arrow legend should be horizontal, pointing in the direction of the associated signalised crossing.
- Where one push-button is mounted in a narrow median, the arrow legend should have a horizontal double-headed arrow parallel to the crosswalk lines.

The use of arrow legends with horizontal pointing arrows (as in in Figure H 1) was found to be better for pedestrians with cognitive impairments.

Figure H 1: Push-button location and orientation



H.5 Distance from Signalised Crossing

The push-button should be located not more than 1 m outside the projection of the signalised crossing not more than 2 m back from the kerb line at the signalised crossing.

H.6 Push-button Posts

A special push-button post should be installed if no traffic signal post can be located in a suitable position.

H.7 Audio-tactile Buttons

These should not be closer than 2 m from one another (AS 1742.14). For this reason, two push-buttons on one pole are not suitable for audio-tactile push-buttons.

Appendix I Traffic Signal Special Situations

This appendix presents examples of special situations that may occur at signalised intersections including:

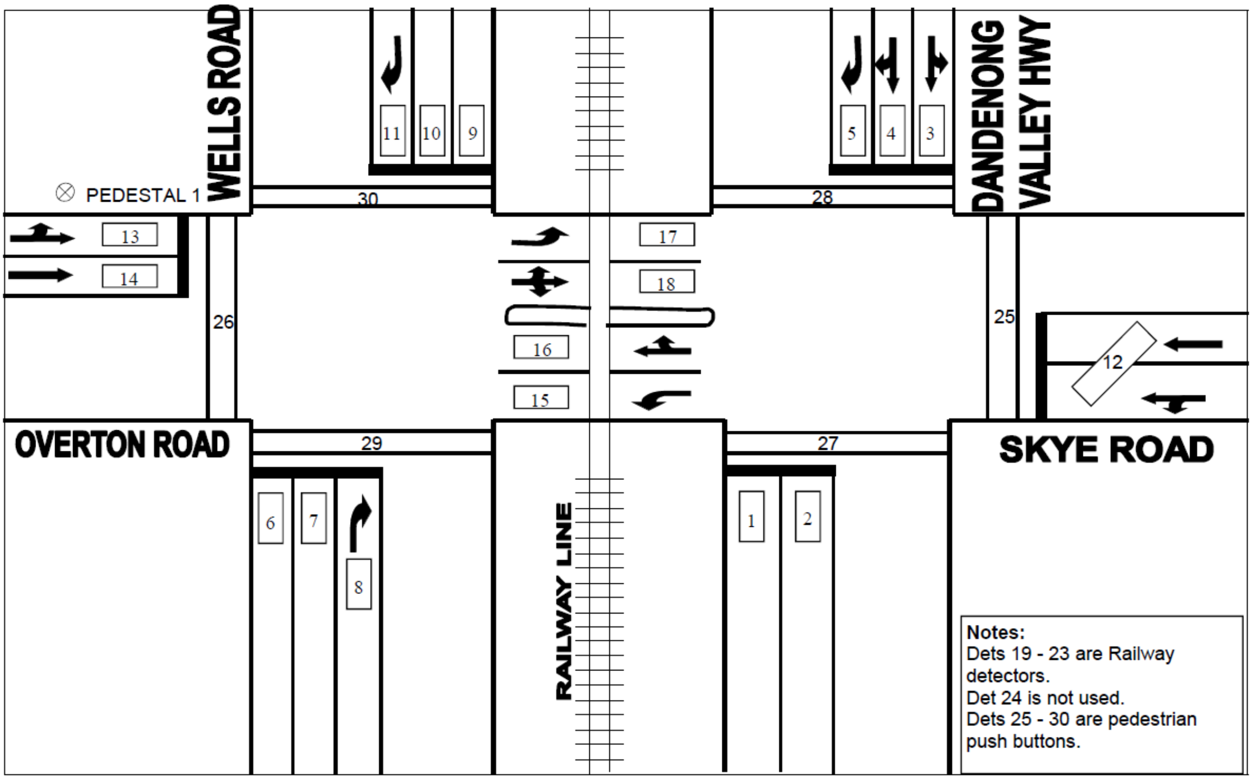
- a railway level crossing between paired intersections
- signalised intersection with bus priority phases.

These examples present methods of accommodating special situations in traffic signal phasing, timing and detection. However, it should be noted that jurisdictional practices may vary or be applicable to a specific brand and model of traffic controller used. Considerable experience and expertise may be necessary to implement control for these situations. Jurisdictional, manufacturer or other professional expertise should be consulted to obtain advice on appropriate phasing sequence options, inputs or other critical elements.

I.1 Railway Level Crossing Between Paired Intersections

An example of traffic signals interlinked with a railway level crossing is shown in Figure I 1. At this location, a railway level crossing passes between a pair of traffic signals. This location must therefore consider any queuing issues at the internal approaches due to the closely spaced intersections during general operation. Additionally, special phases must be provided at the signalised intersections for when a train is approaching or within the level crossing area.

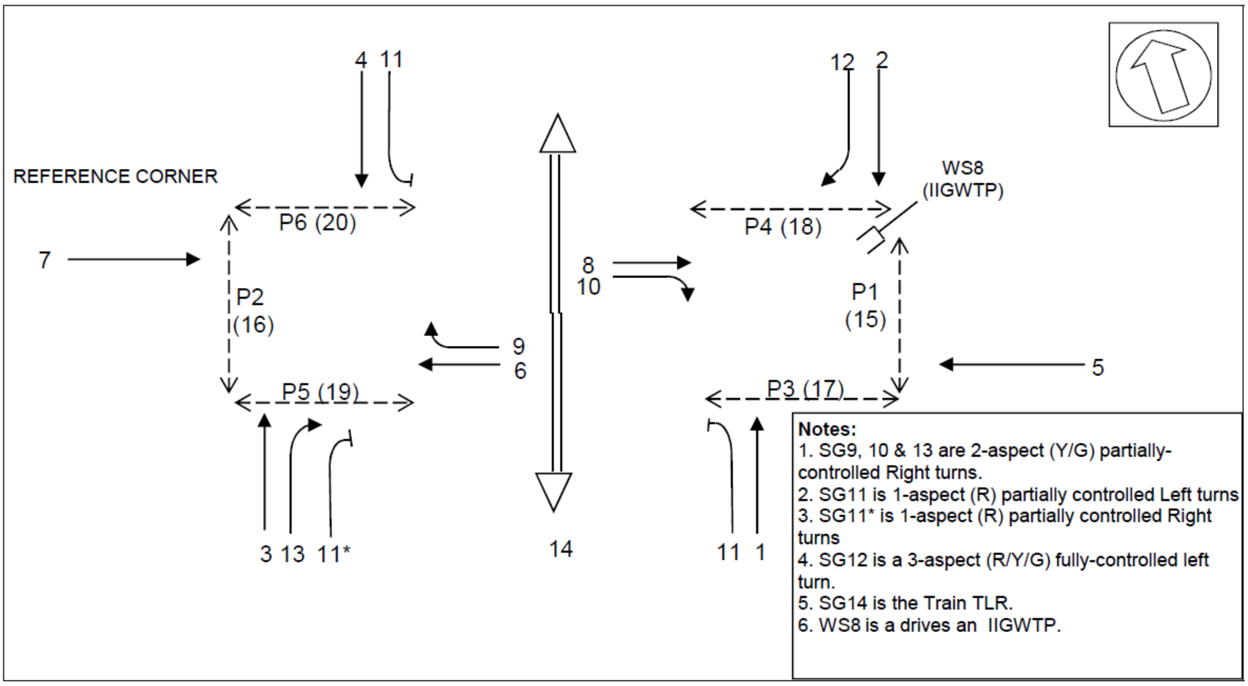
Figure I 1: Location of detectors



Source: VicRoads (unpublished).

Figure I 2 displays the control group allocation at the intersection. As shown, Signal Group (SG) 14 corresponds with the traffic light response (TLR) that occurs when a train approaches or is at the level crossing.

Figure I 2: Control group allocation



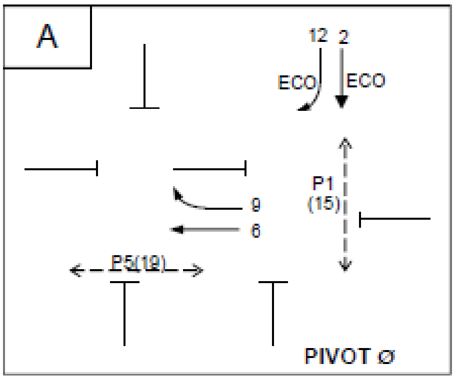
Source: VicRoads (unpublished).

Figure I 3 shows the phasing diagram for the intersection. Phases A, B, C, D and E operate during typical vehicular demands at the intersection. The phasing is configured to minimise internal queuing between the paired intersections. For example, during Phase A while Skye Road and the Dandenong Valley Highway SG2 and SG12 operate, SG8 and SG9 operate at the Wells Road and Overton Road intersection. An early cut-off (ECO) is used to terminate SG2 and SG12 prior to SG8 and SG9 to minimise internal queuing. During Phases B, C and D, similar pairings and ECO operation occurs at upstream signal locations.

When a train approaches a level crossing, Phase F is activated to clear the level crossing tracks prior to a train arrival. The internal signal groups (i.e. 6, 8, 9 and 10) operate during Phase F to clear any traffic within the level crossing area. Phases G1 and G2 operate while a train is at the level crossing. During Phases G1 and G2, the railway level crossing prevents vehicle passage. Other signal groups crossing the level crossing tracks are given a red display during this time period (i.e. Signal Groups 6, 8, 9, 10 and 11). SG11 and SG11* are partial one-aspect displays showing a red arrow during Phases F, G1 and G2 preventing vehicles from turning while the railway level crossing controls (i.e. flashing lights and boom gates) are operating.

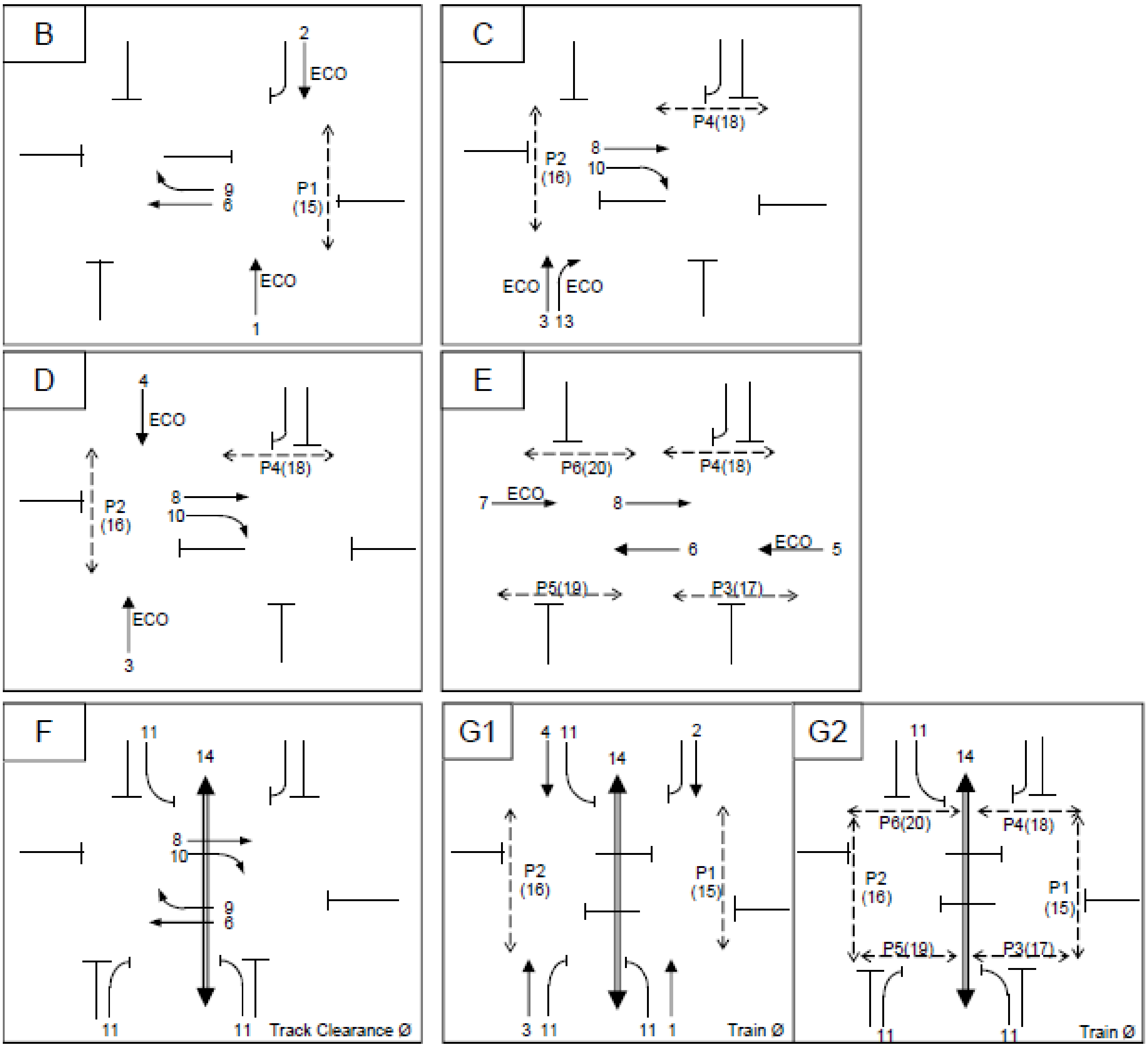
Controller timing settings are shown in Table I 1.

Figure I 3: Phasing diagram



Refer General Notes

PHASE	PROHIBITED PHASE CHANGES TO	REVERSION ON MAXIMUM	MAXIMUM V.I.G ON REVERSION



V.A. SEQUENCE ABCDE

Source: VicRoads (unpublished).

Table I 1: Controller timing settings

Controller time settings								
Description	**Time setting no.**	**Phase**						
		A (1)	**B (2)**	**C (3)**	**D (4)**	**E (5)**	**F (6)**	**G (7)**
Red/yellow	1	–	–	–	–	–	–	–
Late start	2	3	–	3	–	–	3	–
Minimum green	3	8	8	8	8	8	4	8
Increment	4	–	–	–	–	–	–	–
Maximum initial green*	5	–	–	–	–	–	–	–
Maximum extension green	6	30	25	15	15	20	6	**
Early cut off	7	4.0	4.0	4.0	4.0	4.0	–	–
Yellow	8	4.0	4.0	4.0	4.0	4.0	4.0	4.0
All red	9	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Special all red	10	–	–	–	–	–	–	–
Gap 1	11	2.5	2.5	3.0	2.5	2.5	2.5	–
Gap 2	12	3.0	2.5	–	0.0	2.5	2.5	–
Gap 3	13	–	2.5	–	2.5	–	–	–
Gap 4	14	–	2.5	–	0.0	–	–	–
Headway 1	15	1.2	0.6	1.6	0.6	0.6	0.6	–
Headway 2	16	0.6	1.2	–	1.2	0.6	0.6	–
Headway 3	17	–	0.4	–	0.5	–	–	–
Headway 4	18	–	0.3	–	1.2	–	–	–
Waste1	19	8	7	7	7	7	4	–
Waste 2	20	8	7	–	7	7	4	–
Waste 3	21	–	7	–	7	–	–	–
Waste 4	22	–	7	–	7	–	–	–

* Maximum initial green = minimum green + variable initial green.
** Refer to special purpose time settings no. 9 and 10.

Pedestrian time settings									
Description	**Time setting no.**	**Pedestrian**							
		P1 (17)	**P2 (18)**	**P3 (19)**	**P4 (20)**	**P5 (21)**	**P6 (22)**	**P7 (23)**	**P8 (24)**
Delay	1	–	–	–	–	–	–	–	–
Walk*	2	8.0	8.0	8.0	8.0	8.0	8.0	–	–
Clearance 1	3	8.0	9.0	7.0	9.0	7.0	10.0	–	–
Clearance 2	4	1.0	1.0	1.0	4.0	4.0	1.0	–	–

* Minimum walk time – used in Isolated and Flexilink operation

Special purpose time settings		
Time setting no.	**Time setting (Range: 0–200)**	**Function**
9	20	SG1 and SG2 max extension green in train Phase (GØ)
10	20	SG3 and SG4 max extension green in train Phase (GØ)

Source: VicRoads (unpublished).

I.2 Signalised Intersection with Bus Priority

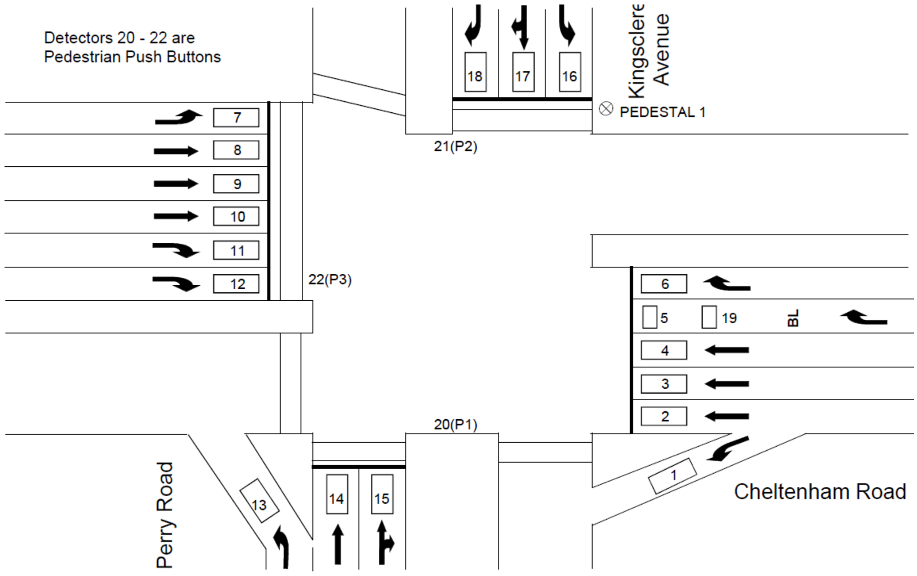
The intersection shown in Figure I 4 provides an example of bus priority phases, including a special phase and an early start for buses.

In Figure I 4, a bus lane approaches from Cheltenham Road that turns right onto Kingsclere Avenue. Signal Group 8 is assigned exclusively to the bus lane (Figure I 5). As shown in the phasing diagram (Figure I 6), a special right turn phase for buses operates during Phase E.

During Phases B, G1 and G2, buses turn right with general vehicular traffic (i.e. SG5). However, buses (i.e. SG8) receive an early start. A single aspect white 'B' display is used to facilitate the special bus phase and early start operation. For further guidance on bus signal displays, refer to Part 10 of the Guide to Traffic Management (Austroads 2019d).

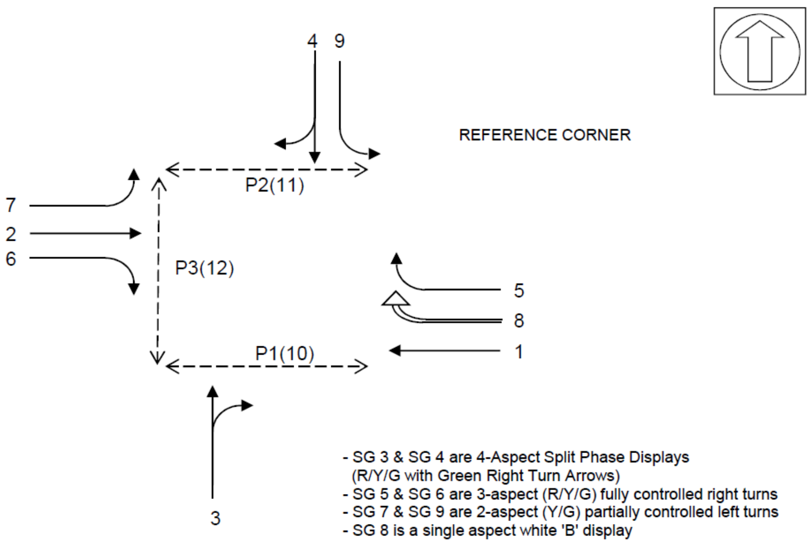
Controller timing settings are shown in Table I 2.

Figure I 4: Location diagram and detector map



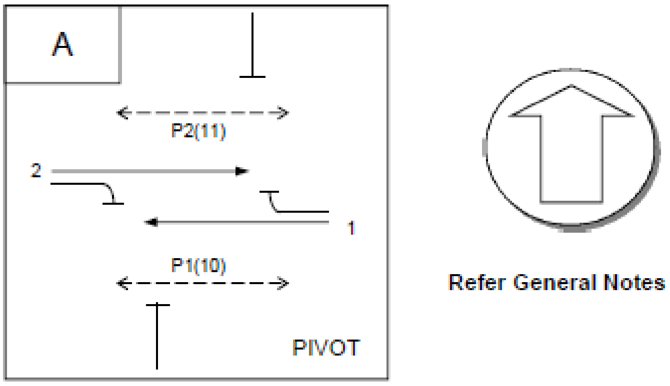
Source: VicRoads (unpublished).

Figure I 5: Control group allocation

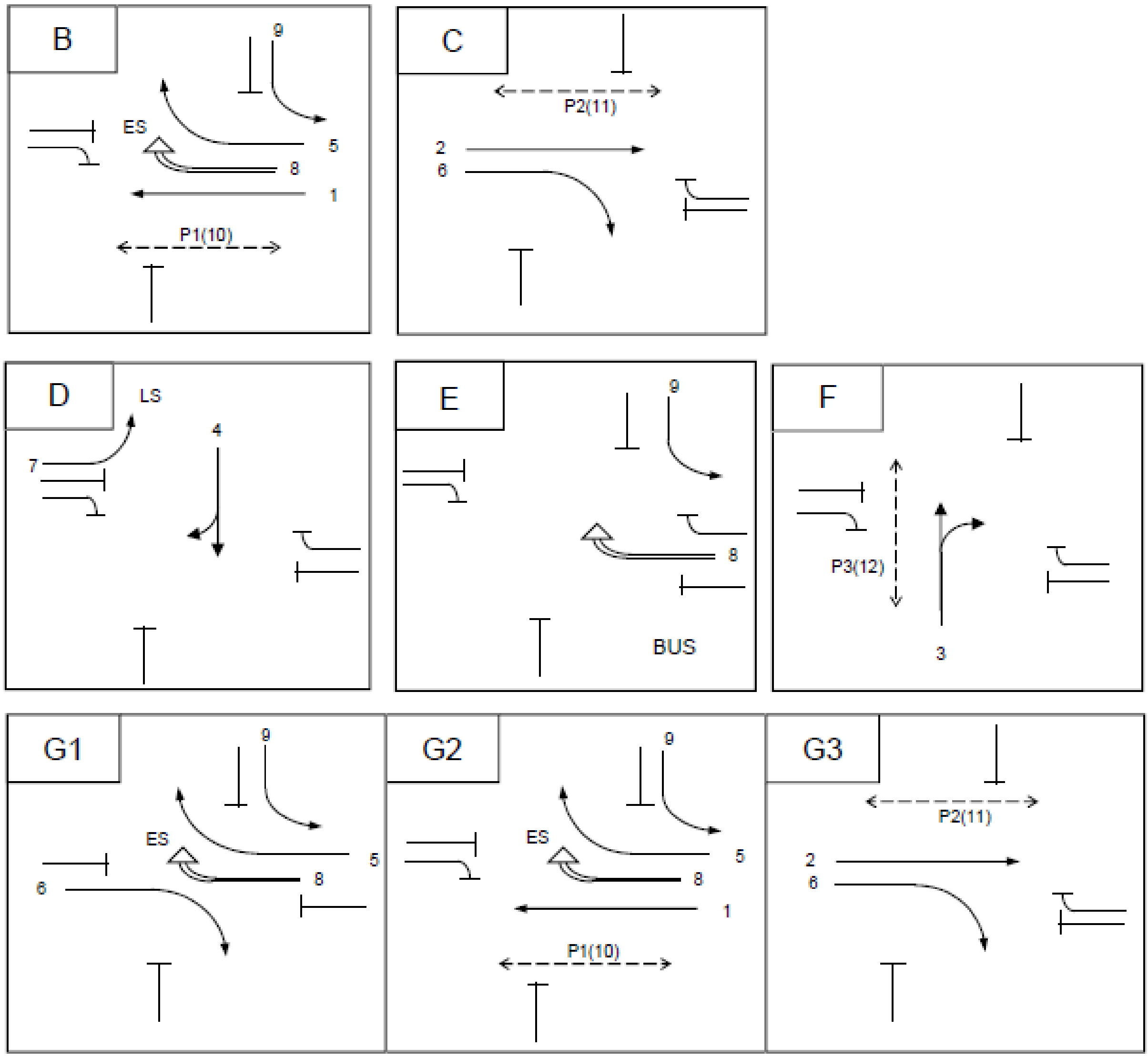


Source: VicRoads (unpublished).

Figure I 6: Phasing diagram



PHASE	PROHIBITED PHASE CHANGES TO	REVERSION ON MAXIMUM	MAXIMUM V.I.G ON REVERSION



V.A. SEQUENCE ADEFG

Source: VicRoads (unpublished).

Table I 2: Controller timing settings

Description	Time setting no.	Phase						
		A (1)	B (2)	C (3)	D (4)	E (5)	F (6)	G (7)
Red/yellow	1	–	–	–	–	–	–	–
Late start	2	–	1	–	1	–	–	1
Minimum green	3	10	11	6	8	5	8	11
Increment	4	–	–	–	–	–	–	–
Maximum initial green*	5	–	–	–	–	–	–	–
Maximum extension green	6	30	0	0	20	0	20	20
Early cut off	7	–	–	–	–	–	–	–
Yellow	8	4.5	4.5	4.5	3.5	3.0	4.0	3.0
All red	9	2.0	2.5	2.5	4.0	2.5	3.0	4.0
Special all red	10	–	4.0	4.0	3.5	4.0	2.5	–
Gap 1	11	2.5	2.5	2.5	2.5	–	2.5	2.5
Gap 2	12	2.5	2.5	2.5	2.5	–	–	3.5
Gap 3	13	2.5	2.5	2.5	–	–	–	2.5
Gap 4	14	–	–	–	–	–	–	–
Headway 1	15	0.4	0.4	1.2	1.2	–	0.6	0.6
Headway 2	16	1.2	0.6	0.4	0.6	–	–	0.6
Headway 3	17	0.4	1.2	0.6	–	–	–	1.2
Headway 4	18	–	–	–	–	–	–	–
Waste 1	19	7	7	7	7	–	7	7
Waste 2	20	7	7	7	7	–	–	10
Waste 3	21	7	7	7	–	–	–	7
Waste 4	22	–	–	–	–	–	–	–

* Maximum initial green = minimum green + variable initial green.

Pedestrian time settings

Description	Time setting no.	Pedestrian							
		P1 (17)	P2 (18)	P3 (19)	P4 (20)	P5 (21)	P6 (22)	P7 (23)	P8 (24)
Delay	1	–	–	–	–	–	–	–	–
Walk*	2	15.0	15.0	15.0	–	–	–	–	–
Clearance 1	3	4.0	7.0	11.0	–	–	–	–	–
Clearance 2	4	2.0	–	3.0	–	–	–	–	–

* Minimum walk time – used in Isolated and Flexilink operation.

Special purpose time settings

Time setting no	Time setting (Range: 0–200)	Function
9	4	SG 5 and SG 9 special maximum in GØ (XSF 5)
10	4	SG 6 special maximum in GØ (XSF 6)
11	5	Timer 'A' – SG 8 early start
12	6	BØ alternate minimum green (ref. page 4/3)
13	6	GØ alternate minimum green (ref. page 4/3)

Source: VicRoads (unpublished).

Appendix J Traffic Signal Pre-Commissioning Checklist

1. Ensure that an insulation check in accordance with AS/NZS 3000 has been completed prior to switching on the controller and detectors; generally the relevant electricity supply authority will not provide connection to mains supply unless their special requirements and those of AS/NZS 3000 have been met.
2. Ensure that the controller has been tested in the workshop for compliance with the controller programming procedures (Section 6.7) and phasing requirements of the design.
3. Check vehicle detectors for correct operation (presence or passage), and ensure that the loop detection zone does not encroach on other lane streams.
4. Check pedestrian push-button assemblies to verify the operation of pedestrian indicators, orientation of the arrows, the audio-tactile operation including sound levels, and the connection of the audio-tactile functions to the correct Walk displays.
5. Energise the controller (but with lamp circuits off) and check the operation in response to demands from vehicle, bus, tram and pedestrian detectors; where special detectors (e.g. for fire stations and trains) are provided these should be similarly checked; and detector presence times should be checked.
6. Momentarily energise each lamp circuit to ensure that the intersection has been wired correctly, i.e. that signal faces not associated with the circuit being energised are not energised.
7. Check that the signal faces for each approach are in accordance with the design plan.
8. Check signal faces for correct aiming and coverage by visual inspection from each approach lane (Part 10 of the Guide to Traffic Management) (Austroads 2019d).
9. Check signal visors and louvres to ensure that sun phantoms are acceptably low and that signal cut-off in relation to conflicting movements has been achieved (Part 10 of the Guide to Traffic Management) (Austroads 2019d).
10. Check that the flashing yellow mode and start-up sequence operate correctly.
11. With lamp switching circuits energised, check the operation of the signal groups by cycling the controller through all of its phases; this is a further check that the controller programming applied to the site is correct.
12. Check that the site communicates to the central computer if applicable.
13. Check that any necessary changes to the design are recorded and that information specific to the site is documented; complete documentation is essential to facilitate maintenance.
14. Check that the lane configuration and pavement markings are in accordance with the design plan.
15. Check that the required signs have been installed and redundant signs removed (Part 10 of the Guide to Traffic Management) (Austroads 2019d).
16. Check that the kerbside controls have been installed.
17. Check that the fault reporting sign has been installed on the signal controller (Part 10 of the Guide to Traffic Management) (Austroads 2019d).

Appendix K Traffic Signal Monitoring and Evaluation Checklist

The following checks should be made when monitoring and evaluating the operation of a site:

1. Are the signs and road markings appropriate to the phasing as designed?
2. Are the kerbside controls adequate for the required capacity of the site?
3. Are traffic flows actually as predicted or assumed?
4. Is traffic avoiding the signalised site and creating congestion elsewhere?
5. Is equipment (controller) operating as designed?
6. Are signal phasings and timings (Section 6.7.12 and Appendix G) adequate to ensure that:
7. The yellow times in relation to vehicle stopping characteristics, and times provided between phases to clear traffic from the controlled area are satisfactory?
8. Traffic is not held unnecessarily at a red signal when adequate gaps exist in a running movement?
9. Are delays to vehicles and pedestrians on each approach at satisfactory levels?
10. Are the numbers of vehicles left in a queue at the termination of the green period and the number of vehicles stopped more than once in each queue at satisfactory levels?
11. Is the occurrence of queue overflows from turning lanes blocking other movements minimised?
12. If coordination exists, are good progressions being obtained as planned? (Section 6.9)
13. Does platooning by upstream signals or interference from downstream signals indicate a need for coordination? (Section 6.9)
14. Are vehicle detector loops appropriately located to detect traffic as intended in both the passage and presence mode, and is waiting traffic standing in the position anticipated in the design? (Section 6.8)
15. Are unusual vehicles being missed by detectors, and are they in sufficient numbers to justify special detection techniques?

Appendix L Traffic Signal Techniques to Support Network Operation Planning Toolkit

The *Signal Management Toolkit* has been developed as part of research project NT1909: *Signal management techniques to support network operations* (Austroads 2015e). The purpose of the Toolkit is to assist road agencies in the identification and assessment of signal management techniques that will support the intent of the network operation plan (NOP). This guidance is particularly relevant to Stage 5 of the NOP process (development of traffic management, operation and improvement plans) and undertaking of a network fit assessment (NFA). Refer to Austroads (2016a) for description of the NOP process and NFA.

The Toolkit assists to assess the impact of different signal management techniques on various road user needs. Road user groups included are general traffic, freight, public transport, pedestrian and cyclist. The Toolkit assess impacts for road users in the direction or movement directly impacted by the treatment and road users travelling in the conflicting directions or movements.

The Toolkit broadly covers level-of-service needs of road users such as:

- mobility (i.e. delay)
- safety
- access (i.e. level of restrictions to movements, for example banned movements at an intersection will degrade access).

Refer to Austroads (2015d) for details on the level of service needs for various the road users. Many traffic signal techniques impact not just mobility but also aspects of safety and access to get a better understanding of impacts and the trade-offs involved.

The Toolkit seeks to raise awareness of practitioners to potential impacts of proposed techniques that may not have otherwise been considered as part of the decision-making process. It will allow practitioners to demonstrate the alignment of the technique with the NOP and thereby assist in justifying its use to other stakeholders.

The Toolkit is primarily intended for planning purposes, not for detailed operations. It does not provide detailed impact assessments for each site-specific application of a technique. Those techniques with a wide range of impacts across applications may require further investigation to determine the likely impacts for a specific context. The conclusions of the NFA should be sensitive to the potential ranges of impacts.

The Toolkit is available in Excel format (downloadable from the Austroads website) and an abbreviated static version is provided in Table L 2.

The toolkit is essentially a table of likely impacts of various traffic signal techniques. The impact is rated from ‘significant positive impact’ to ‘significant negative impact’ as shown in Table L 1.

The term impact is defined as a change in level-of-service relative to a baseline, wherein the baseline assumes:

- signalised intersection (i.e. all movements protected) with no/equal priorities.
- pedestrian crossings are provided, i.e. fully protected parallel walk
- cyclists are allowed to use the pedestrian phase but need to dismount.

Table L 1: Label for impacts of signal management techniques

Impact	Label used in the Toolkit (Table L 2)
Significant positive impact	+ + +
Medium positive impact	+ +
Low positive impact	+
No impact	0
Low negative impact	-
Medium negative impact	- -
Significant negative impact	- - -

The impact assessment in Table L 2 is indicative only, and includes a range where appropriate, depending on different applications. Real impacts will vary depending on site characteristics and other factors, which should be considered in the assessment process.

Also, more than one technique may be implemented at an intersection concurrently; however, this assessment only considers impacts separately. Combined impacts may need to be investigated further.

Table L 2: Impact assessment for signal management techniques (impacts are indicative only)

Name	Impacts for road users travelling in direction of treatment							Impacts for road users travelling in conflicting directions to the treatment						
	Outcome	Private motorist	Tram	Bus	Pedestrian	Cyclist	Freight	Outcome	Private motorist	Tram	Bus	Pedestrian	Cyclist	Freight
Baseline	Mobility	0	0	0	0	0	0	Mobility	0	0	0	0	0	0
	Safety	0	0	0	0	0	0	Safety	0	0	0	0	0	0
	Access	0	0	0	0	0	0	Access	0	0	0	0	0	0
Techniques that support public transport priority														
Green extension/ phase extension	Mobility	+	+ to ++	+ to ++	0	+	+	Mobility	-	-	-	-	-	-
Recall/red truncation or early green/priority green/phase early-start	Mobility	0 to +	+ to +++	+ to +++	0 to +	0 to +	0 to +	Mobility	-	-	-	- to 0	- to 0	-
	Safety	0	0 to +	0 to +	0	0	0	Safety	0	0	0	0	0	0
Additional phase in signal cycle to clear queues in front of buses/trams	Mobility	+	+ to +++	+ to +++	+	+	+	Mobility	-	-	-	-	-	-
	Safety	0	0 to +	0 to +	0	0	0	Safety	0	0	0	0	0	0
Priority phase sequences	Mobility	Varies + / -	++ to +++	++ to +++	Varies + / -	Varies + / -	Varies + / -	Mobility	-- to -	-- to -	-- to -	-- to -	-- to -	-- to -
	Safety	0	0 to +	0 to +	0	0	0	Safety	0	0	0	0	0	0
Phase suppression (of conflicting movements)	Mobility	0 to ++	+ to +++	+ to +++	0 to ++	0 to ++	0 to ++	Mobility	--- to --	-- to 0	-- to 0	--- to --	--- to --	--- to --
	Safety	0	0 to +	0 to +	0	0	0	Safety	0	0	0	- to 0	- to 0	0
	Access	- to 0	0 to +	0 to +	- to 0	- to 0	- to 0	Access	-- to 0	-- to 0	-- to 0	-- to 0	-- to 0	-- to 0
Public transport priority phase with dedicated lanes	Mobility	--- to -	+++	+++	- to 0	- to 0	--- to -	Mobility	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0
	Safety	0	+	+	0	0	0	Safety	0	0	0	0	0	0
Public transport priority phase with queue-jump lanes	Mobility	-	++ to +++	++ to +++	- to 0	-	-	Mobility	-	-	-	-	-	-
	Safety	0	0 to +	0 to +	0	0	0	Safety	0	0	0	0	0	0
Priority movement repetition in cycle	Mobility	0 to +	+ to ++	+ to ++	0 to +	0 to +	0 to +	Mobility	-- to -	-- to -	-- to -	-- to -	-- to -	-- to -
Reduced cycle time	Mobility	- to --	+	+	0 to +	0 to +	- to --	Mobility	-	-	-	0 to +	0 to +	-

Name	Impacts for road users travelling in direction of treatment							Impacts for road users travelling in conflicting directions to the treatment						
	Outcome	Private motorist	Tram	Bus	Pedestrian	Cyclist	Freight	Outcome	Private motorist	Tram	Bus	Pedestrian	Cyclist	Freight
Gating to an area for queue management	Mobility	Varies + / -	+ to ++	+ to ++	0	0	Varies + / -	Mobility	Varies + / -	Varies + / -	Varies + / -	0	0	Varies + / -
Techniques that support freight priority														
Longer signal cycle times (higher minimum cycle times)	Mobility	0 to +	- to 0	- to 0	- to 0	0 to +	+	Mobility	-- to 0	-- to 0	-- to 0	-- to 0	-- to 0	-- to 0
	Safety	0 to +	0	0	0	0	+	Safety	0	0	0	0	0	0
Coordinating signal offsets for heavy vehicles	Mobility	- to 0	0 to +	0 to +	0	0	+ to ++	Mobility	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0
	Safety	- to 0	0	0	0	0	+	Safety	0	0	0	0	0	0
Green extension/dwell phase extension/early start	Mobility	0 to +	0 to +	0 to +	0 to +	+	+ to +++	Mobility	-	-	-	-	-	- to 0
	Safety	0	0	0	0	0	+ to ++	Safety	0 to +	0 to +	0 to +	+ to ++	+ to ++	0 to +
Techniques that support pedestrian priority														
Exclusive signal phase for pedestrians	Mobility	-- to -	-- to -	-- to -	Varies + / -	-- to -	-- to -	Mobility	-- to -	-- to -	-- to -	Varies + / -	-- to 0	-- to -
	Safety	0 to +	0 to +	0 to +	+ to +++	0 to +	0 to +	Safety	0 to +	0 to +	0 to +	+ to +++	0 to +	0 to +
Exclusive 'scramble crossing' or 'Barnes dance' phase	Mobility	-- to -	-- to -	-- to -	+	-- to -	-- to -	Mobility	-- to -	-- to -	-- to -	+	-- to -	-- to -
	Safety	0 to +	0 to +	0 to +	+ to +++	0 to +	0 to +	Safety	0 to +	0 to +	0 to +	+ to +++	0 to +	0 to +
	Access	0	0	0	++	0	0	Access	0	0	0	++	0	0
Double/half cycling	Mobility	-	0 to +	0 to +	+	+	-	Mobility	- to 0	- to 0	- to 0	0 to +	- to 0	- to 0
	Safety	0	0	0	0 to +	0	0	Safety	0	0	0	0 to +	0	0
Dwell on red for all users, or dwell on walk (green) for pedestrians	Mobility	-- to -	-- to -	-- to -	0 to +++	Varies + / -	-- to -	Mobility	-- to -	-- to -	-- to -	0 to +++	Varies + / -	-- to -
	Safety	0 to +	0 to +	0 to +	0 to ++	0 to +	0 to +	Safety	0 to +	0 to +	0 to +	0 to ++	0 to +	0 to +
Extended clearance intervals	Mobility	- to 0	- to 0	- to 0	0 to ++	0 to +	- to 0	Mobility	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0
	Safety	0	0	0	+ to ++	0 to +	0	Safety	0	0	0	0	0	0
Extended walk/stretch walk/rest in walk	Mobility	- to 0	- to 0	- to 0	+ to ++	0 to +	- to 0	Mobility	0	0	0	0	0	0
	Safety	0	0	0	Varies + / -	0 to +	0	Safety	0	0	0	0	0	0

Name	Impacts for road users travelling in direction of treatment							Impacts for road users travelling in conflicting directions to the treatment						
	Outcome	Private motorist	Tram	Bus	Pedestrian	Cyclist	Freight	Outcome	Private motorist	Tram	Bus	Pedestrian	Cyclist	Freight
Reduced cycle lengths	Mobility	- to 0	Varies + / -	Varies + / -	+	+	- to 0	Mobility	-	-	-	+	+	-
	Safety	0	0	0	+	+	0	Safety	0	0	0	+	+	0
Pedestrian detection and variable green man interval	Mobility	- to 0	- to 0	- to 0	+	- to 0	- to 0	Mobility	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0
	Safety	0	0	0	+	0	0	Safety	0	0	0	0	0	0
Fixed demand	Mobility	- to 0	- to 0	- to 0	+	Varies + / -	- to 0	Mobility	- to 0	- to 0	- to 0	+	Varies + / -	- to 0
	Safety	0	0	0	+	+	0	Safety	0	0	0	+	+	0
Puffin crossing	Mobility	Varies + / -	Varies + / -	Varies + / -	Varies + / -	Varies + / -	Varies + / -	Mobility	Varies + / -	Varies + / -	Varies + / -	0	Varies + / -	Varies + / -
	Safety	0	0	0	0 to ++	0	0	Safety	0	0	0	0	0	0
Isolated traffic controls at areas with high pedestrian demand	Mobility	- to 0	- to 0	- to 0	+	Varies + / -	- to 0	Mobility	- to 0	- to 0	- to 0	+	Varies + / -	- to 0
	Safety	- to 0	- to 0	- to 0	0	- to 0	- to 0	Safety	- to 0	- to 0	- to 0	0	- to 0	- to 0
Pedestrian countdown timers	Mobility	0	0	0	0 to +	0 to +	0	Mobility	0	0	0	0	0	0
	Safety	0	0	0	Varies + / -	Varies + / -	0	Safety	0	0	0	0	0	0
Reintroduction of pedestrian walk	Mobility	- to 0	- to 0	- to 0	+ to ++	- to 0	- to 0	Mobility	0	0	0	0	0	0
	Safety	0	0	0	0 to +	0	0	Safety	0	0	0	0	0	0
Techniques that support cyclist priority														
Late start for vehicles (early start/leading interval for cyclists)	Mobility	-	-	-	- to 0	+	-	Mobility	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0
	Safety	0	0	0	0	+ to ++	0	Safety	0	0	0	0	0	0
Fully protected parallel crossing for cyclists at shared path crossing	Mobility	0	0	0	0	+	0	Mobility	0	0	0	0	0	0
	Safety	0	0	0	- to 0	+	0	Safety	0	0	0	0	0	0
Extended clearance intervals	Mobility	0 to +	0 to +	0 to +	0 to +	-	0 to +	Mobility	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0
	Safety	0	0	0	0	+	0	Safety	0	0	0	0	0	0
Longer green time for cyclists at shared path crossings	Mobility	0	0	0	0	+	0	Mobility	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0

Name	Impacts for road users travelling in direction of treatment							Impacts for road users travelling in conflicting directions to the treatment						
	Outcome	Private motorist	Tram	Bus	Pedestrian	Cyclist	Freight	Outcome	Private motorist	Tram	Bus	Pedestrian	Cyclist	Freight
Exclusive signal phase for cyclists	Mobility	-- to 0	-- to 0	-- to 0	-- to 0	++	-- to 0	Mobility	-- to 0	-- to 0	-- to 0	-- to 0	-- to 0	-- to 0
	Safety	0 to +	0 to +	0 to +	0 to +	++	0 to +	Safety	0 to +	0 to +	0 to +	0 to +	0 to +	0 to +
Activation of green signal phase when cyclists are detected	Mobility	- to 0	- to 0	- to 0	- to 0	+	- to 0	Mobility	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0
	Safety	0	0	0	0	+	0	Safety	0	0	0	0	0	0
Signal coordination for cyclist priority	Mobility	-	- to 0	- to 0	0	++	-	Mobility	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0
	Safety	- to 0	- to 0	- to 0	0	+	- to 0	Safety	0	0	0	0	0	0
Arterial reversion	Mobility	0	0	0	0	0 to +	0	Mobility	0	0	0	0	0	0
	Safety	0	0	0	0	0 to +	0	Safety	0	0	0	0	0	0
Cyclist bypass lanes at T-intersections	Mobility	0	0	0	0	+	0	Mobility	0	0	0	0	0	0
	Safety	0	0	0	0	- to 0	0	Safety	0	0	0	0	0	0
Mid-block crossing signals for cyclists	Mobility	N/A	N/A	N/A	0	+	N/A	Mobility	0	0	0	0	0	0
Mid-block crossing signals for cyclists	Safety	N/A	N/A	N/A	- to 0	0 to +	N/A	Safety	0	0	0	0	0	0
	Access	N/A	N/A	N/A	0	+	N/A	Access	0	0	0	0	0	0
Techniques that support general traffic priority														
Improved signal coordination/ progression	Mobility	+ to +++	0 to +	0 to ++	- to 0	Varies + / -	+ to ++	Mobility	- to 0	- to 0	- to 0	0	0	- to 0
	Safety	0 to +	0 to +	0 to +	0	0 to +	0 to +	Safety	0	0	0	0	0	0
Banned right-turns	Mobility	+ to ++	+ to ++	+ to ++	0 to +	0 to +	+ to ++	Mobility	0 to +	0 to +	0 to +	0	0	0 to +
	Safety	0	0	0	0 to +	0 to +	0	Safety	0	0	0	0	0	0
	Access	-	-	-	0	0	-	Access	0	0	0	0	0	0
Skip right-turns every second cycle (peak times)	Mobility	+	+	+	0 to +	0 to +	+	Mobility	0 to +	0 to +	0 to +	0 to +	0 to +	0 to +
	Safety	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0	Safety	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0
	Access	-	-	-	0	0	-	Access	0	0	0	0	0	0
Maximum time transfer/stealing	Mobility	+	+	+	0 to +	+	+	Mobility	Varies + / -	Varies + / -	Varies + / -	0	Varies + / -	Varies + / -
Gating to an area	Mobility	Varies + / -	Varies + / -	Varies + / -	0 to +	Varies + / -	Varies + / -	Mobility	Varies + / -	Varies + / -	Varies + / -	0	Varies + / -	Varies + / -
	Safety	0	0	0	0 to +	0	0	Safety	0	0	0	0	0	0

Name	Impacts for road users travelling in direction of treatment							Impacts for road users travelling in conflicting directions to the treatment						
	Outcome	Private motorist	Tram	Bus	Pedestrian	Cyclist	Freight	Outcome	Private motorist	Tram	Bus	Pedestrian	Cyclist	Freight
SCATS Incremental Split Selection and Variation Routine 83 (for congestion management)	Mobility	0 to +	0 to +	0 to +	0 to +	0 to +	0 to +	Mobility	Varies + / -	Varies + / -	Varies + / -	0	0	Varies + / -
Pedestrian parallel walk	Mobility	+	+	+	+	+	+	Mobility	0 to +	0 to +	0 to +	0 to +	0 to +	0 to +
	Safety	-	- to 0	- to 0	-	0	- to 0	Safety	0	0	0	0	0	0
Late start for vehicles (early start/leading interval for pedestrians) – partially protected parallel walk	Mobility	0 to +	0 to +	0 to +	0 to +	0 to +	0 to +	Mobility	0 to +	0 to +	0 to +	0 to +	0 to +	0 to +
	Safety	- to 0	- to 0	- to 0	- to 0	- to 0	- to 0	Safety	0	0	0	0	0	0
Pelican crossing	Mobility	N/A	N/A	N/A	0	0 to +	N/A	Mobility	0 to +	0 to +	0 to +	0	0 to +	0 to +
	Safety	N/A	N/A	N/A	-	- to 0	N/A	Safety	-	-	-	-	-	-
Two-staged crossing at wide intersections	Mobility	+ to ++	+ to ++	+ to ++	- to --	Varies + / -	+ to ++	Mobility	+ to ++	+ to ++	+ to ++	0	0 to ++	+ to ++
	Safety	0	0	0	-	0	0	Safety	0	0	0	0	0	0

Legend:

positive and positive/neutral = green

neutral = amber

negative and negative/neutral = red

negative to positive range = dark grey

N/A means not applicable.

Commentary 1 Inter-Agency Coordination for Incident Management

Inter-agency coordination and cooperation are key to effective incident management operations. The primary agencies involved in traffic incident management include organisations responsible for road traffic and transport; police, fire and rescue and ambulance services; and response, towing and recovery providers. Usually the lead agencies for traffic incident management initiatives are road traffic agencies and police services. The following discussion is based on (Austroads 2007a).

C1.1 Multi-agency Roles and Responsibilities

Organisations typically responsible for incident management and typical roles and responsibilities are outlined in Table 3.3 of the main text.

Other stakeholders include those affected by, or interested in, traffic incidents such as:

- media, traffic reporters, traffic information providers
- transit, freight, taxi operators
- user groups – motorist, freight
- tourist groups
- facilities dependent on reliable traffic (e.g. airport, port)
- researchers, consultants.

C1.2 Formal Agreements

Responding agencies have different goals, perspectives, responsibilities, priorities and operating cultures, which can cause misunderstandings, disagreements, delays, and inefficiencies in resolving traffic incidents. Establishing formal agreements or memoranda of understanding can help. These cover desired joint outcomes, roles and responsibilities, governance, incident command structure, equipment staging, traffic control, hazardous materials incident issues and procedures, crash investigation procedures, quick clearance procedures and can also set performance goals such as response time or incident clearance time.

The Washington State Patrol (WSP) and Washington State Department of Transportation (WsDOT) signed a Joint Operations Policy Statement in March 2006 (WSP & WsDOT 2006) to document the joint policy positions regarding issues of mutual interest in the operations of Washington State Highways. It includes policy and procedures for:

- data sharing, joint facilities
- traffic management and traveller information
- incident response, incident response teams, service patrols, quick clearance, incident command system
- event planning and work zone safety
- policy performance measures
- policy training.

The Roads and Maritime Services of New South Wales has a comparable memorandum of understanding with police.

C1.3 Multi-agency Teams

Formalised multi-agency teams are a mechanism for accomplishing the established goals and objectives of the traffic incident management program and ensuring its continuity beyond administration and personnel changes.

Typically, these teams are comprised of senior (mid-to-upper level management) representatives of each of the participating agencies plus private sector partners. They meet regularly (e.g. monthly) and deal with information exchange, inter-agency cooperation, policy issues, conduct training exercises (desktop or field), organise post-incident briefings and plan for special event incident response.

At an operational level multi-agency team arrangements may extend, as in New South Wales, to the joint preparation of operational plans with the police and the presence of a police officer in the traffic management centre operated by the road agency.

C1.4 Incident Command System

The incident command system (ICS) is a systematic tool used for the command, control, and coordination of an emergency response. An ICS allows agencies to work together using common terminology and operating procedures for controlling personnel, facilities, equipment, and communications at a single incident scene (Federal Highway Administration 2006b).

Safe and timely clearance of traffic incidents requires coordination of response resources. This requires a clear command hierarchy, designated responder roles and responsibilities, clear procedures, and the ability of all responders to communicate clearly and effectively throughout the response and clearance processes.

Coordinating response resources from the various responding organisations is crucial to the safe and timely clearance of traffic incidents.

This requires:

- clear command hierarchy where each person reports to only one designated person
- designated responder roles and responsibilities
- clear procedures
- the ability of all responders to communicate clearly and effectively by standardising the terminology being used.

The incident command structure is inherently flexible and easily adapted to different incident response efforts and agency needs and has the following characteristics:

- common organisational structure – involving on-scene officials that represent each jurisdiction and/or functional agency with statutory authority for an incident
- single command post – agencies are allowed to operate harmoniously and share essential planning and operations functions
- unified planning process – a consensus set of incident objectives and strategies is identified prior to commencing tactical operations, which is used to develop an action plan that addresses priorities and provides unified tactical operations and resource assignments
- unified resource management – coordinated use of available resources is facilitated without agencies having to sacrifice administrative and policy control over their resources

- an incident command post led by an incident commander whose role is to:
  - possess clear authority and knowledge of agency policy
  - ensure incident safety
  - establish the incident command post
  - determine incident objectives and strategies to be followed
  - establish immediate priorities
  - initiate, maintain, and control the communications process within the ICS organisation
  - coordinate multi-jurisdictional traffic management and control operations
  - manage planning meetings as required
  - approve, implement, and evaluate the incident action plan
  - approve requests for additional resources or for the release of resources
  - ensure completion of incident after-action reports.

C1.5 Institutional Arrangements: Recommended Practice

Austroads (2007a) lists the following recommendations for institutional arrangements:

- develop a good understanding of stakeholder roles and responsibilities, legislative authority and associated arrangements and encourage sharing of resources and capabilities
- identify and facilitate incident response champions at management and operational levels
- develop a cooperative/collaborative approach, agree on roles and responsibilities, including the use of an incident command system and establish a protocol for the control of incident sites involving inner and outer cordons
- establish a multi-agency traffic incident management team to work together to address priority policy and operational issues
- establish a forum and governance mechanism to share information, build relationships, undertake training, review achievements and take decisions on policy and funding
- formalise agreements between key incident responders covering agreed joint outcomes, roles and responsibilities, governance, quick clearance procedures, incident command structure, traffic control and performance goals
- establish a unified command system incorporating all the key responders, especially the road and traffic agencies
- undertake multi–agency training exercises, including an incident command system and debrief after major incidents to identify lessons learned
- undertake risk assessments and develop planned incident responses for agencies involved
- gather and report data on costs and benefits.

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Commentary 2 Performance of Advanced Traffic Signal Control Strategies

Gartner et al. (1995) investigated the development of advanced traffic signal control strategies and considered the performance realised by their implementation. To compare different control strategies, a hierarchy was developed based on different generations of traffic signal control. This ranged from simpler control strategies, such as fixed-time control (i.e. 0-GC) to more complex strategies, such as fully adaptive traffic control (i.e. 3-GC).

A literature review was conducted of published reports noting the benefits realised when implementing more complex traffic signal control strategies. The results of the comparison are illustrated in Figure C2 1 with:

- Figure C2 1(a) showing the expected improvement
- Figure C2 1(b) indicating the benefits realised.

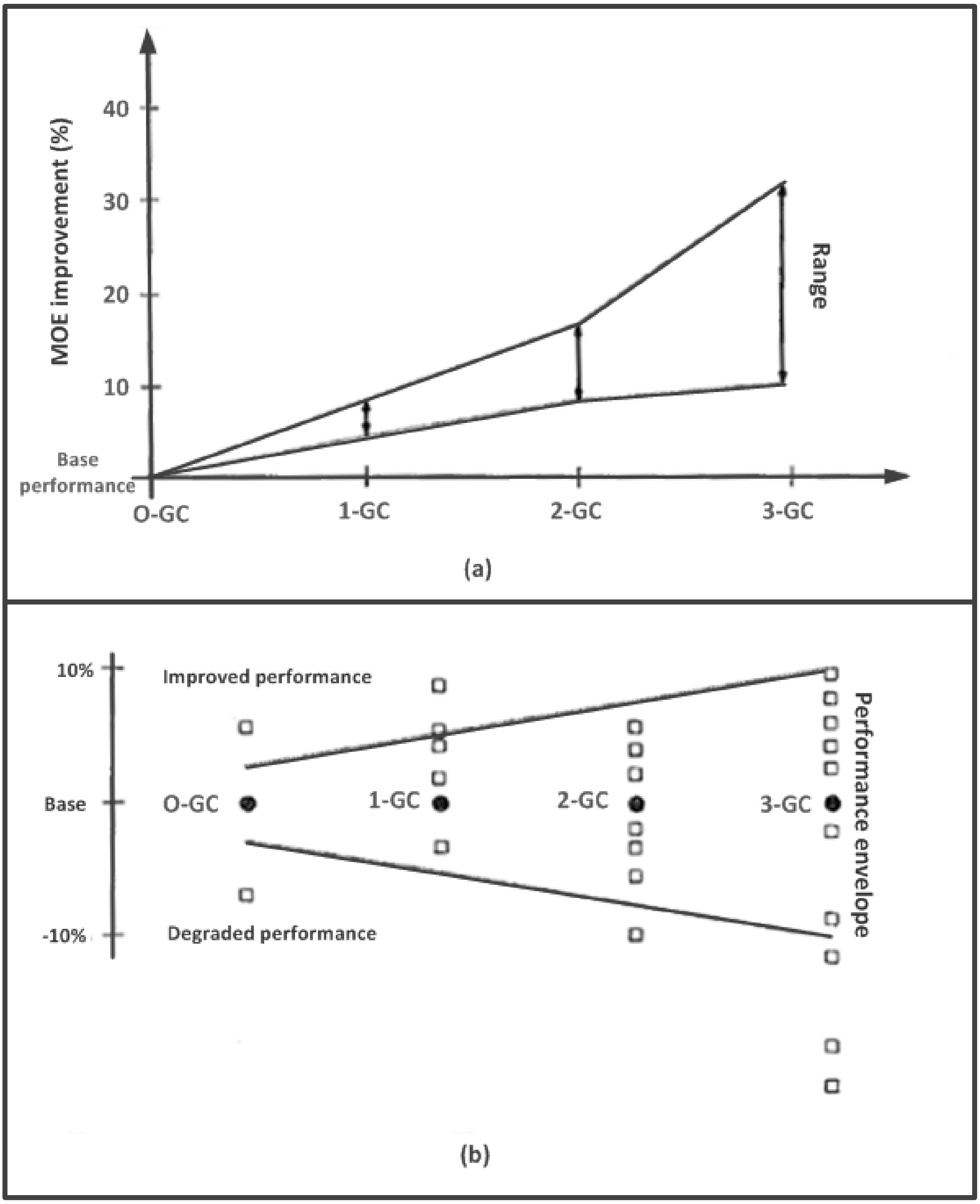
As shown in Figure C2 1(b), a number of field implementations of more complex control strategies reported did not lead to improved performance. The authors identified a number of factors that may have contributed to the degradations in performance such as:

- inaccurate prediction of cycle time resulting in strategies that were unable to respond to rapid changes in traffic flow
- frequent transition of signal timing resulting in considerable delays
- local optimisation of cycle times resulting in dis-benefits due to a loss of synchronisation among intersections in a network.

The authors stressed the importance of continuous monitoring and evaluation of control strategies to ensure that optimal performance is realised when applying more complex control strategies.

Whilst this example is specific to traffic signal control systems, it presents similar issues that need to be considered for other forms of ITS. Namely that substantial effort may be required to configure systems to operate optimally. Additionally, regular review of configuration data may often be required to ensure a system continues to operate optimally in the face of changing traffic environments.

Figure C2 1: Expected and reported performance for traffic signal control generations



Source: Gartner et al. (1995).

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Commentary 3 Broader Transport Operations Function

Increasingly the traffic operations function is being recognised as just one component of a broader transport operations function. In addition to commonly understood traffic management activities, transport operations also address such things as the management of:

- pedestrian movements including their seamless interface with public transport nodes
- public transport priority measures involving bus lanes and traffic signals
- emergency vehicle priority measures such as automatically generated green light corridors and special access arrangements to special events and venues
- transport for special events and venues that often involve coordinating access and egress arrangements for both public transport, private vehicles and pedestrians.

Transport operations, in this context, is not the business of actually running public and other transport services. Rather, it is the range of activities that:

- influences decisions made by public and other transport providers
- supports public transport arrangements for routine operations
- supports public and other transport services during special events or during major incidents when these activities will or may potentially impact the road network.

An integrated approach to transport operations essentially requires a coordinated series of diverse activities involving many stakeholders. These activities start at a policy level affecting the provision of transport infrastructure and services. They end with a member of the community making a trip using any one or a number of different modes, being informed about travel conditions along the journey and expecting that ‘someone’ or ‘something’ is managing their journey in real time.

It is perhaps appropriate that if any one agency should be leading in establishing an integrated approach to transport operations it should be a ‘road based’ authority; all modes of transport are dependent on roads in one way or another.

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Commentary 4 Site Management After Incident

At the scene of a traffic incident the incident commander is responsible for site management while the site is made safe, traffic is managed through and around the scene, investigations are conducted and evidence collected and the site is cleared of wrecked vehicles and debris before reopening to traffic. The incident commander is generally a police officer, unless there is a fire or hazardous material involved, in which case the fire service is in control until that situation has been properly dealt with.

A key objective in site management is ensuring the safety of all responders, those involved in the incident and other road users. To be effective, responders at the incident site need accurate information about progress towards clearance and equipment needed to complete the clearance.

Effective site management requires continual assessment of the site and the needs of the responders and an understanding of the priorities of other responders.

Site management is the process of:

- accurately assessing the incident and scene
- establishing priorities
- establishing a command post as the focal point for communications and command of activities
- neutralising any hazards or fire
- ensuring extraction of the injured, and transporting to hospital
- marshalling resources and response requirements

- ensuring the safety of responders and motorists
- notifying and coordinating responses from appropriate agencies and organisations
- maintaining clear communications with responders and control centres
- managing traffic at the scene of the incident
- undertaking necessary investigations of any criminal activity and for the coroner
- clearing damaged vehicles, arranging for site clean-up and re-opening the road to traffic.

It is important to frequently review what can be done to improve safety and traffic movement at an incident scene, including estimating the remaining incident duration and providing an update to the control centre to ensure responders and motorists are being kept informed.

The objectives of incident site management include:

- ensuring the safety of crash victims, responders and road users
- coordinating activities of all responders involved
- minimising the impacts of the incident on traffic, e.g. reduce congestion, travel time delay
- maintaining effective inter-agency communication
- maximising the use of inter-agency staff and equipment resources.

To assist in effective site management, it is important to have comprehensive up-to-date resource lists, such as:

- contact lists of responders by area – for police, fire, medical, traffic, towing – including alternative contacts if the responder is already on call or otherwise not available
- contact lists of specialist responders – rescue, crash investigation, vehicle safety, environment, hazardous material, structural engineer, etc.
- lists of available equipment and locations – towing and recovery, traffic control, site clean-up
- available supplies and materials to absorb spills
- locations of hospitals, fire stations, police, road works depots, etc.
- copies of any inter-agency agreements.

There are also resource lists of specialist resources and materials:

- treatments for oil/chemical/hazardous material spills
- specialist medical/intensive care paramedics, helicopter evacuation
- specialist recovery equipment – fork lifts, cranes, air bags for lifting heavy items
- mobile traffic control centre – portable camera and communications
- portable equipment – emergency lighting, variable message sign, traffic signals, speed limit signs, etc.

One of the key tasks in incident site management is controlling traffic at the scene, particularly to maintain responder and public safety. Maintenance of traffic flow around the incident scene, once the injured have been attended to, is also an important means of reducing congestion and delay and also reducing the risk of secondary incidents.

Application of traffic control measures near the incident scene can be initially undertaken by the first responder whether police, fire or incident response unit. It is important to get traffic moving safely as soon as possible and this can be achieved through positive traffic control – providing clear delineation of the path through an incident scene and having a controller continuously directing traffic past the scene. This achieves both objectives of getting traffic moving and maximising safety.

Incident scenes should be considered as a temporary work zone, with all the attendant requirements of using the appropriate traffic control devices, allowing sufficient buffer zones for responder safety and emphasising traffic awareness for responders.

Incident scenes are dangerous work places, so careful attention must be given to ensure that occupational health and safety issues are carefully considered. There are a number of other issues that have been determined from consideration of management practice:

- reducing the duration of incidents is important as the occurrence of secondary incidents is directly related to exposure
- traffic control at the scene of an incident is too often not the key focus when responders are concentrating on rescue, investigation and recovery aspects
- all responders may not understand basic traffic control and hence may prefer to block all traffic
- there needs to be clear responsibility for different tasks – rescue, investigation, clean-up, traffic control – which is understood by all responders.

Badly located positioning of response vehicles is also a recurring issue that can make access for responders difficult and reduce traffic flow. Establishment of staging areas off-site is useful, calling up equipment and vehicles when they are required at the scene.

Emergency lighting discipline is another area of concern, as high intensity flashing lights can tend to cause drivers to be dazzled, creating a distraction leading to slowing passing vehicles.

One area that is often forgotten is early deployment of clean-up resources, as it may take some time to get the required equipment, such as road sweepers, to an incident site.

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Commentary 5 Clearance of Incidents

Incident clearance is a multi-agency process with a single objective under the incident command structure approach – to safely remove roadway obstructions and restore the flow of traffic. Actual clearance times are generally not documented in a comprehensive fashion, making it difficult to assess and improve agency performance. Reducing clearance times has the greatest potential benefit in improving overall incident management times – hence reducing delay, congestion and secondary incidents.

Clearance times can decrease when the proper resources are dispatched to the scene. Inter-agency cooperation among fire and rescue, service patrols, law enforcement, and towing and recovery is critical to improving incident clearance performance. Through inter-jurisdictional training, incident management personnel gain a better understanding of other agencies' concerns and missions and facilitate communications, thereby improving clearance times.

Documentation of incident clearance times will enable better understanding of incident clearance performance and allow for improvements in the future.

The objectives of incident clearance include ensuring the safety of responders, crash victims and other motorists and removing the incident blockage from the road as quickly as possible.

The process of clearance includes:

- extrication of trapped victims in road crashes
- making the site safe – addressing hazardous conditions
- crash investigation – collection of data and evidence
- site clearance – removal of debris, wreckage, spilled materials.

Quick clearance refers to a suite of initiatives aimed at reducing the time taken to clear traffic incidents. Traditionally there has been a reluctance to be swift about clearance, but with some of the biggest legal claims developing in the US relating to secondary incidents and the increasing cost impacts of long incident closures, increased interest is being taken in quick clearance approaches. Doing the job swiftly, while using good common sense is better than being cautious in terms of liability implications, i.e. removing vehicles/debris off the road to enable quicker return to normal traffic flows and complementing this approach with reduced liability legislation to protect responder agencies. Quick clearance policy aims to authorise the quick removal of disabled or wrecked vehicles from travel lanes. An open roads policy encourages incident responders to rapidly remove disabled or wrecked vehicles, spilled cargo and debris that obstruct traffic. It is also important to set performance targets, such as ‘all incidents are cleared from the roadway within 90 minutes of the arrival of the first responder’.

Stronger partnerships and agreed operating procedures need to be developed between the key responders using inter-agency agreements aimed at improving quick clearance through joint operations protocols. In addition, regular training exercises and ongoing forums for regular discussion of policy and operational issues are required.

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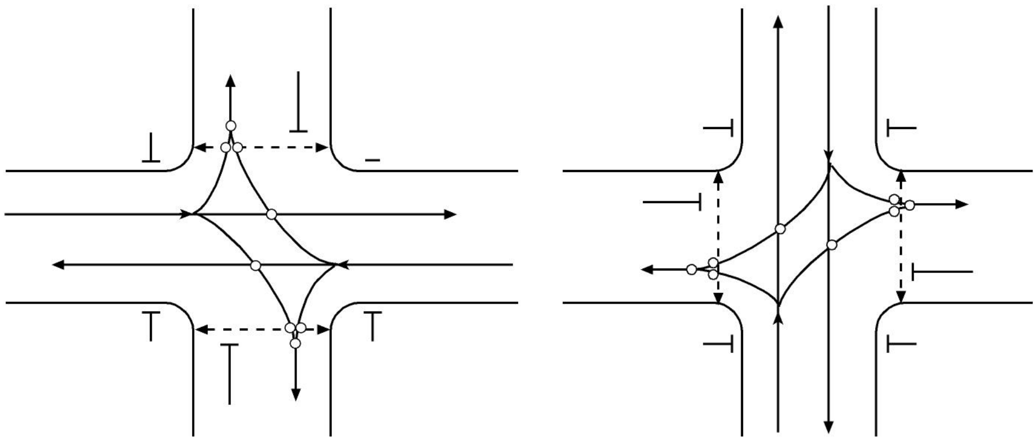
Commentary 6 Conflict Points of a Two-Phase Signal

A two phase signal system retains four turning conflicts between right turn and through vehicles, four merge conflicts between right turn and left turn vehicles, and eight turning vehicle-pedestrian conflicts (i.e. a total of 16 conflict points) as shown in Figure C6 1.

Figure C6 1: Conflict points in the two phase system



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Commentary 7 Inductive Loop Detector

To construct an inductive loop detector, several turns of wire are placed in a slot cut in the road pavement. The wire is connected via a feed cable to a detector sensor unit mounted in the controller cabinet or on a signal post. Presence or movement of a vehicle (as a large mass of metal) over a loop reduces the loop inductance and causes a detector output. This output is the closure of a relay contact or the equivalent operation of a semiconductor.

Some detector sensor units can distinguish buses from the shape of the detector output and hence a different type of inductance loop detector might be used for such purposes.

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Commentary 8 SCATS Degree of Saturation

DS in the SCATS traffic signal control system is an abbreviation for **degree of saturation.** It is formulated as shown in Equation C1 (Austroads 2007d).

$$DS = (GT - S_{act} + n\ S_{MF}) \times 100\%/GT \qquad \text{C1}$$

where

GT = is the green time (s)

S_{act} = is the total space time in that green period (s)

S_{MF} = is the space at saturation or maximum flow (s/veh)

n = is the number of spaces counted (veh)

Equation C1 gives the ratio of green time used by vehicles to the available green time, a measure of how well a green period is being used. It is not precisely the same as the usual definition of degree of saturation in traffic flow theory, which is the arrival flow or demand divided by the capacity. It should be noted that true demand is difficult to measure with a point sensor especially if the sensor is at the stop line. SCATS is able to estimate oversaturation by choosing an appropriate length for the inductive loop sensor.

The DS equation has been effective as a feedback control parameter in optimising signal phases and cycle times. DS is also a reasonable indicator of congestion including the situations when DS is greater than 1.

To identify over-saturation due to recurrent congestion or incidents, SCATS uses DS and two traffic volumes: Vo the number of vehicles recorded in a green period, and V_k the **reconstituted volume** in that green period, given by Equation C2:

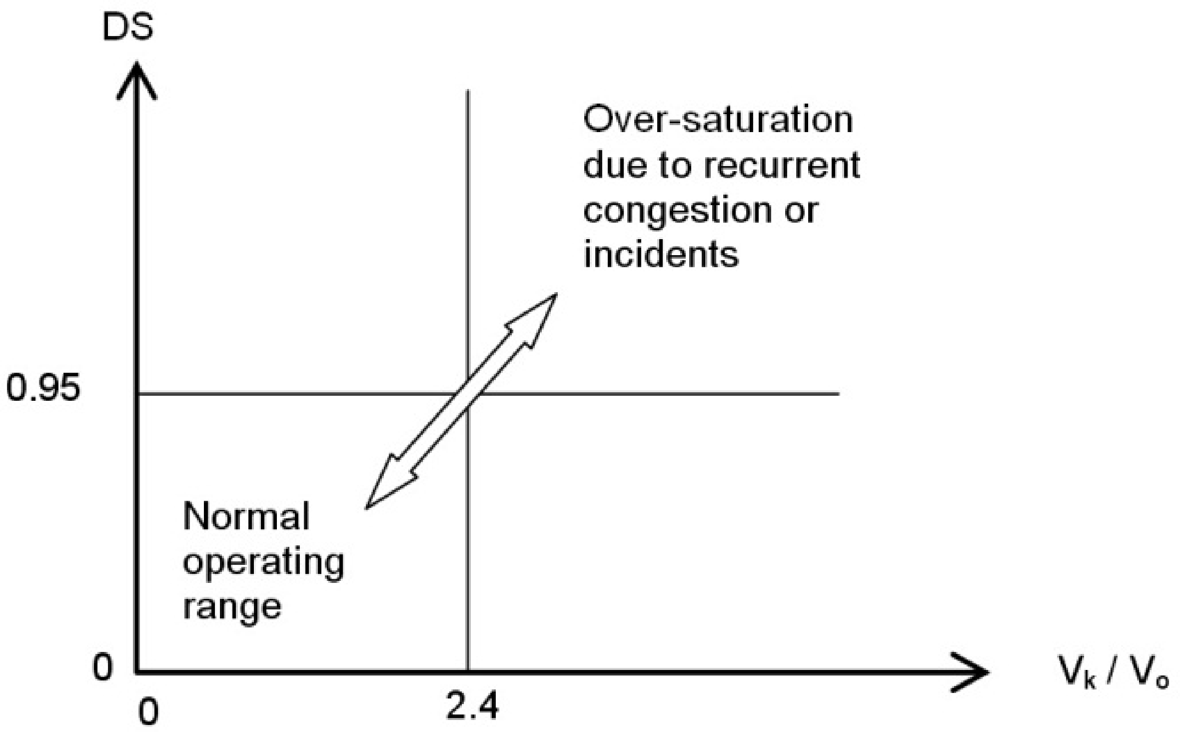
$$V_k = DS \times GT \times MF \qquad \text{C2}$$

where

MF = the maximum flow (veh/s)

The identification of congestion is specified in Figure C8 1. The ratio V_k/V_o must exceed 2.4 and the DS must exceed 0.95. This top right-hand quadrant represents situations when the system reliably indicates congestion.

Figure C8 1: SCATS congestion indicator



Source: Austroads (2007c).

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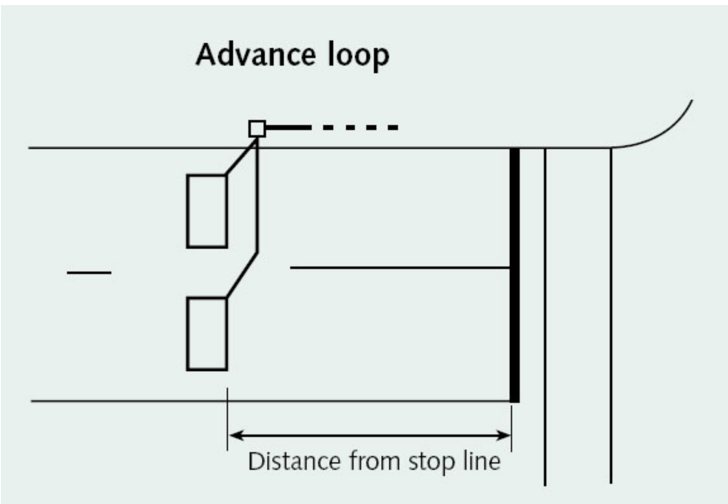
Commentary 9 Advance Loop Detectors

Advance detector loops may be used in addition to the normal stop line detectors. They can be set in presence or passage mode. In the passage mode of operation an inductive loop detects the passage of a vehicle passing over the loop, however, it does not detect the duration the vehicle is over the loop as in the presence mode. Advance detector loops may also be used without stop line detectors as shown in Figure C9 1.

Figure C9 1: Advance loop



Generally, advance detector loops are located at a distance from the stop line that corresponds to the actuated signal gap setting. Under light to moderate traffic conditions the use of advance detectors can lead to a reduction in delays and stops under light to moderate traffic flows by tending to:

- provide an advance call for a relevant phase
- avoid the termination of a green display when a vehicle is in the 'dilemma zone'.

Advance loops are able to terminate phases earlier, since assessment of gaps can be made several seconds before it can be detected at the stop line.

Several considerations also apply to advance detector loops. In some control strategies, advance detectors are used in a gap-seeking role on high-speed approaches or where there is a large number of heavy vehicles to enable the onset of a gap to be identified earlier. However, because of the long distance from the stop line, they have the following shortcomings:

- They are not as effective as stop line detectors in identifying turning movements if placed upstream of exclusive turning lanes.
- Demands lodged are processed on the assumption that vehicles do not change lanes or turn off before reaching the stop-line.
- Vehicles entering the roadway between the detector loop and the stop line are not detected, or vehicles leaving the roadway between the detector loop and the stop line are detected unnecessarily.
- They cannot detect slow-moving vehicles, queues or stationary vehicles if operating in passage mode.
- Arbitrary provisions have to be made for the green time requirements for traffic trapped between the detector loop and the stop line at the start and end of the phase.
- Excessive allowances need to be made for the time necessary for individual vehicles to travel from the loop to the stop line during the green interval.
- The further the detector is located away from the controlled area (i.e. the stop line), the less accurately it is able to respond to changes in traffic flowing into the controlled area (e.g. a decrease in capacity and queue formation).
- The installation of detector loops far in advance of the stop line is generally unattractive from an economic point of view.

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Commentary 10 Design Considerations Related to Signal Coordination

When undertaking the design of a signalised intersection, it is important to consider the effects that signal coordination will have on the design. The major effects relate to the following factors.

- Traffic signal controller selection
  - a traffic signal coordination scheme will require the use of controllers that are compatible with the type of coordination adopted.
- Detector placement and function
  - in many cases, the detection system required will be specified by the type of master control system to be installed. Detector placement and function options include, individual lane detectors, approach detectors, stop line detectors, advance detectors or queue detectors.
- Cycle and phase timing
  - determination of a common system cycle time and phase green times is discussed in Section 6.9.

- Phasing design
  - the phasing design of signals needs to consider the coordination requirements Section 6.5.3. For example, it may be necessary to vary the phase sequence to achieve two-way coordination, and this may not be apparent until the system progression strategy has been determined
  - some isolated signal features such as conditional pedestrian movements can irregularly interrupt associated traffic movements and impair progression or capacity. These features should be removed by redesign of the intersection phasing.
- Side road and pedestrian delay
  - at intersections in a coordinated system, there could be an increase in delays to vehicles entering from side roads and pedestrians crossing the main route compared with operation on an isolated traffic-actuated basis due to a longer cycle time imposed by the critical intersection in the system. Therefore, careful consideration must be given to this factor to ensure minimisation of this adverse effect, e.g. through sub-area optimisation in order to reduce the cycle time.
- Public transport
  - the needs of public transport should be considered in the overall design. Benefits to public transport may be achieved by either introducing a passive bias to the signal settings, or by actively responding to the presence of a public transport vehicle to adjust the signal operation. It may also be possible to relocate bus or tram stops at certain critical points.

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Commentary 11 Timing Strategies to Improve Safety During the Clearance Phase

Traffic signals may be altered to assist vehicles in safely clearing signalised intersections upon the termination of a green signal display. The type of changes may include increasing yellow, all-red or green time. Timing changes may be implemented during all time periods. Research has also been conducted to selectively activate clearance timing changes to target specific types of vehicles, such as heavy freight vehicles.

Changes in yellow, all-red and extension of green time are typically used to assist a vehicle in safely clearing an intersection by minimising negative effects to the traffic signal dilemma zone. A dilemma zone pertains to the predicament of an approaching vehicle, at the onset of a yellow signal, being too close to an intersection to stop safely and comfortably, and yet too far from it to clear the conflict area (refer to Appendix G.4.6).

Dilemma zone protection is a method whereby vehicle detectors are used to minimise the effects of the dilemma zone. By basing this type of protection on heavy vehicles characteristics, this type of treatment may assist a heavy vehicle with safely traversing intersections.

Archer and Young (2008) investigated five alternate traffic signal treatments intended to reduce the crash-risk of heavy vehicles associated with red-light running at intersections. The investigation was based on variations of extending green time, changes to yellow and all-red time on the basis of a heavy vehicle dilemma zone. A micro-simulation analysis was used to measure the impacts upon an intersection in the outer Melbourne metropolitan area. Results suggested that increasing the yellow time had the greatest effect on reducing red-light violations. However, the authors cautioned that due to known behavioural adaptation effects of yellow time changes, the overall impact may deteriorate relatively quickly. Alternatively, the authors suggested a more sustainable solution providing significant safety benefits may be to extend green time for long vehicles caught in the dilemma zone and also extend all-red time in situations where any vehicle type was determined to have a high probability of red-light running.

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Commentary 12 Real-time Travel Estimation

The Melbourne travel time system (known as Drive Time) utilises a network of inductive loop detectors installed in Melbourne's freeways. Detector stations at 500 m spacing each comprise two loops per lane. Detector data is aggregated in 20 s time slices. These two parameters were originally designed to control the response of a system in detecting incidents on freeways, but have been found useful also for travel time calculation (Luk et al. 2006).

Luk et al. (2006) describe the travel time estimation process in the following terms:

- The three traffic parameters from a detector station are speed, occupancy and flow per lane. They are usually averaged over a measurement time slice to obtain, e.g. the average spot speed at a station, from which travel time between two stations can be derived and displayed to motorists as in the Drive Time System. Because the spot speeds are time mean speeds that are higher than space mean speeds, there is generally a bias in the estimated travel time.
- Another issue is the way a segment or route travel time is calculated. The displayed time and the three-colour column on a Drive Time sign are based on the prevailing traffic conditions. The conditions experienced by a driver passing by a sign are not necessarily the same conditions when the driver arrives at a destination. The displayed travel times often show a lag during shoulder peak periods. For example, a displayed time of 40 min at the Springvale end on the Eastern Freeway in Melbourne at 9 a.m. is an overestimation of the actual travel time because the same driver will experience less congestion at the Punt Road (city-end) by the time of arrival there. This lag can be overcome by making use of historical travel times, although the use of historical data negates the benefit of a real-time system, especially when non-recurrent congestion or incidents occur.

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Commentary 13 Pedestrian Protection

Protection for pedestrians must always be considered (Roads and Traffic Authority NSW 2008c). The degree of protection provided depends on the circumstances and may be:

- full protection by a red arrow or red roundel for the whole walk and clearance intervals
- timed protection by a red arrow for the whole of the walk interval and part of the clearance interval followed by a flashing yellow for part or all of the remainder of the clearance interval
- timed protection by a red arrow for the whole of the walk interval followed by a flashing yellow for part or all of the clearance interval
- timed protection by a red arrow or red roundel for the whole of the walk interval and part of the clearance interval
- timed protection by a red arrow or red roundel for the whole of the walk interval
- timed protection by a red arrow or red roundel for part of the walk interval (this is not to be used for an opposed right turn where that right turn is permitted to filter).

Note that some jurisdictions do not use flashing yellow.

Protection for pedestrians should be provided whenever pedestrians are placed at an unnecessarily high risk.

- Full protection must be provided when:
  - sighting to the pedestrian crossing is restricted
  - the speed of the turning traffic is high
  - there are two lanes of vehicles turning left or right through the pedestrian movement, where those turning vehicles are opposed
  - there are three or more lanes of vehicles turning left or right through the pedestrian movement.

- Timed protection must be provided when:
  - there are two lanes of vehicles turning left or right through the pedestrian traffic, where those turning vehicles are unopposed (flashing yellow arrows must be used after the expiry of the red arrow during the pedestrian clearance interval)
  - where left or right arrow displays are present and there is an associated conflicting movement.
- Timed protection should be considered when:
  - there is a high volume of turning traffic and low pedestrian flow
  - the flow of pedestrian is high
  - there is a high proportion of children, elderly or people with disabilities
  - the length of the crossing results in a long clearance time.

The length of the timed protection depends on the type of pedestrians using the crossing, the flow of pedestrians and the flow of conflicting vehicles. The length of timed protection can be varied by the time of the day such as at school entry and exit times.

Pedestrian protection may be provided at any intersection where it is considered that there is an increased risk to pedestrians due to the number of left or right-turning heavy vehicles.

As a guide, pedestrian protection is usually unnecessary when all of the following conditions are met:

- the crossing is clearly visible
- the flow of turning vehicles is light
- the turn only occurs from one lane
- the speed of the turning traffic is low.

Flashing yellow arrows may be installed to provide additional pedestrian safety to (i) remind drivers of their obligation to give way to pedestrians and (ii) allow vehicles to proceed, if a crossing is clear during the flashing red don’t walk clearance period of the pedestrian phase.

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Austroads' Guide to Traffic Management consists of 13 parts and provides comprehensive coverage of traffic management guidance for practitioners involved in traffic engineering, road design and road safety.

Guide to Traffic Management Part 9: Traffic Operations is concerned with the day-to-day operations that support the provision of road services to road network users. It introduces the concept of traffic operations as underpinning road user services, covers the major types of services provided and outlines the role of intelligent transport systems (ITS) in delivering these services. Part 9 provides guidance on the configuration and operation of systems, both ITS and manual, supporting traffic operations including network monitoring systems, incident management, traffic signal systems, congestion management, freeway/motorway management systems and traveller information systems.

Guide to Traffic Management Part 9

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