Network and asset management: benefits of real-time data

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An important note for the reader

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Executive summary

This report explores the opportunities and challenges of real-time technology and data in supporting network and asset management activities. The objectives of the research were:

- Identify both readily available and emerging technologies that can deliver real-time or near real-time data for network management and asset management purposes.
- Determine typical asset management and network management activities undertaken in New Zealand and recognise the information needs surrounding these activities.
- Identify the opportunities and challenges of providing real-time information to internal and external stakeholders.
- Assess the risks associated with an overreliance on real-time information, particularly for information sources with limited availability or of variable quality.
- Identify a best practice approach to the adoption or adaptation of technologies that provide real-time data.

The report commences with an introduction to network management and asset management and the definition of 'real time'. This definition was not constrained by a specific timeframe but refers to the collection, analysis and dissemination of information as quickly as is practically manageable. The strategic context of technology in transport is also explored.

A literature review explores the range of real-time technologies available for network and asset management purposes. This takes a sensor-first approach, that is identifying the types of sensors available (for example fibre optics, radar, closed circuit television and global navigation satellite systems) and the range of real-time applications for which they have been applied. Communication network technologies and the internet of things are also discussed. Finally, the literature discusses some of the challenges associated with the use of real-time sensors and technologies.

Stakeholder consultation was undertaken with industry experts and technology professionals to understand their network and asset management information needs and the current applications of real-time technologies. Stakeholders were also questioned about emerging technologies and initiatives that they were aware of. The results of the consultation are summarised as key findings, opportunities or challenges. Regarding the timeliness of real-time information, stakeholders generally acknowledged real-time information was more critical for network management activities such as detecting and managing unplanned events, compared with asset management activities as the deterioration of assets is a relatively slow process. Opportunities that were identified included doing more analytics and the fusion of existing and emerging data sources. It was acknowledged that New Zealand is relatively innovative when it comes to developing new network and asset management solutions. Challenges that were identified included the difficulty in making sense of big real-time datasets and the risks of relying on poor quality or incomplete data for decision making.

To coalesce the learnings from the literature review and stakeholder consultation, a classification scheme for technology applications in asset and network management was developed. Six categories (or activity areas) were identified:

- detecting and responding to network incidents
- managing planned events
- monitoring weather impacts

- managing hazards
- asset and site surveying
- structural asset monitoring.

These activity areas were then used to guide the stakeholder workshop in identifying broad opportunities for technology application. The stakeholder workshop was held in May 2017 and involved participants from the NZ Transport Agency (journey managers, network managers and asset integrators) and the Christchurch City Council. The purpose of the workshop was to explore the activity areas in more detail for opportunities and pitfalls. The first part of the workshop involved assessing three interactive case study scenarios, where participants were asked to specify their real-time information needs, opportunities and constraints. The three scenarios were:

1 A rural weather event coupled with a natural hazard incident (eg rockfall or slip)

2 A crash on an urban network near a construction site where traffic management is in operation

3 An asset lifecycle study.

The second part of the workshop involved ranking each activity area in terms of the potential applications for real-time technologies. Network incidents, managing hazards, asset and site surveying and structural asset monitoring (for critical assets) were ranked has having the highest real-time technology needs. Managing planned events and monitoring weather impacts were ranked low due to technologies already being well used and understood in these areas.

The next stage of the research explored two different real-time applications in detail, the first being the use of sensor technologies to detect hazards as part of the North Canterbury Transport Infrastructure Recovery rebuild of the rail and road along the Kaikoura Coast. The second case study explored the use of Google global positioning system (GPS) data and advanced real-time data analytics to monitor congestion around planned works and to detect unplanned incidents on road networks.

To conclude the research, the learnings were collated by identifying strategic opportunities and challenges for developing real-time applications. In summary, the opportunities included:

- improving the speed at which incidents are identified
- exploring the use of predictive real-time modelling to understand the impact of incidents on the wider road network
- improving the detection of defects and hazards
- keeping people safe in high-risk locations
- smarter traffic management around planned events
- emerging opportunities associated with the internet of things and autonomous vehicles
- making better use of existing data sources and technologies.

Challenges associated with real-time technologies included:

- handling ‘big’ real-time datasets
- the range of platforms and products in development and diverging approaches undertaken by different contractors and regions
- integrating the human element of interpreting the outputs of real-time systems

- the expertise required to design and implement real-time technologies
- the lack of communications coverage in rural areas.

Specific recommendations for the implementation of this research and for future study were identified as follows:

1. Work with telecommunications and technology providers to keep informed of advances in technology and the latest available products and opportunities.
2. Given the fast-changing nature in which new technologies and applications are developed, road controlling agencies, contractors and technology providers should use industry forums and conferences as a means of sharing real-time applications, including future opportunities and lessons learned.
3. Undertake a detailed stocktake of data sources and technologies in New Zealand, identifying opportunities to extract greater value from them. This may include:
   a. identifying data sources which are ‘locked’ into proprietary systems, and explore methods for opening this up
   b. undertaking advanced analytics, which could include combining different types of data in innovative ways to provide new insights
   c. improving how the data or application is made available to end-users
   d. improving understanding of the quality of the data to determine how useful it is for decision-making purposes
   e. making data openly available.
4. Seek specialist advice when considering applications that generate or rely on large real-time datasets. Depending on the project, this may include specialists in the fields of big data, the internet of things, software design and delivery, communications and location analytics.

Abstract

Data is essential for understanding the demands placed on road assets and transport networks. There is an opportunity through advances in real-time technologies to improve the delivery of network management and asset management activities. This requires an understanding of both the real-time technologies that are available, and the real-time information needs of network managers and asset managers.

This research investigated the applications of real-time technologies and data in asset and network management. This included identifying a range of opportunities for expanding the use of real-time technology, for example by making better use of existing datasets and improving the detection of incidents and defects. A range of challenges were also identified, including the difficulties of working with 'big' real-time datasets, the risk of reliance on technology and the need for specialist expertise to develop real-time applications.

The outputs of this research include a range of recommendations, including possible real-time technology applications and actions to ensure the transport industry keeps up to date with advances in sensor technologies, analytical platforms and communication networks.

1 Introduction

The NZ Transport Agency ('the Transport Agency') commissioned Abley Transportation Consultants to undertake this research to determine the advantages and disadvantages of real-time technology in supporting network and asset management activities.

The objectives of this research were as follows:

- Identify both readily available and emerging technologies that can deliver real-time or near real-time data for network management and asset management purposes.
- Determine typical asset management and network management activities undertaken in New Zealand and recognise the information needs surrounding these activities.
- Identify the opportunities and challenges of providing real-time information to internal and external stakeholders.
- Assess the risks associated with an overreliance on real-time information, particularly for information sources with limited availability or of variable quality.
- Identify a best practice approach to the adoption or adaptation of technologies that provide real-time data.

The research was undertaken in New Zealand during early 2017 and involved several stages. First, a literature review and stakeholder consultation were completed to identify real-time technologies that are used to support network and asset management activities. Following this, a classification scheme was developed to categorise technologies against asset and network management activity areas. Using this framework, a stakeholder workshop was held to explore these activity areas in more detail. Finally, a case study exercise was undertaken looking at two different applications of real-time technologies and data: the rebuild of the road and rail network along the Kaikoura Coast, and the use of Google global positioning system (GPS) data for monitoring planned and unplanned events on road networks. The findings of the research are distilled in the discussion chapter which identifies specific opportunities and challenges for the use of real-time technologies.

2 Background and strategic context

This chapter introduces network management and asset management and discusses the relevance of real-time information from a strategic government perspective. This chapter also includes key definitions and matters of scope that influence how the research was undertaken and reported.

2.1 Definitions

The definitions of network and asset management were agreed with the research steering group and are as follows:

The purpose of network management activities is:

> *to minimise disruption to road users and maximise the customer experience of a safe, efficient and enjoyable journey within the network* (NZ Transport Agency 2016).

Asset management activities involve:

> *the application of engineering, financial and management practices to optimise the level of service outcome in return for the most cost effective financial input* (Transit New Zealand 2005).

The term 'customer' in this report refers to road users, including individual and commercial users.

2.1.1 Technology focus

This research reviewed a range of technologies and applications for collecting, analysing and communicating information about the road environment. The primary focus, however, was on technologies that provide reliable, real-time information for network and asset managers to enable them to make operational and planning decisions. Less focus was given to communicating real-time information to customers as there is already extensive research in this area undertaken in New Zealand (see (Chang et al 2013; Chang et al 2015).

2.1.2 Real-time focus

In the strictest sense, real-time information is defined as information that is available the moment it is collected. In reality, there is usually a time lag between collecting the data and providing it in a usable format.

The definition of what may be considered real time or near real time was discussed at length with the research steering group and it was decided not to put an explicit definition on what constitutes 'real time'. Instead, a pragmatic approach was adopted for this research whereby real-time information is that which is collected, analysed and disseminated as quickly as is practically manageable to helpfully inform network and asset management activities.

2.2 Asset and network management in New Zealand

The Transport Agency is responsible for operating, maintaining, renewing and improving New Zealand's state highway road network. The Transport Agency places a high importance on data and information management and usage to ensure data processes and documentation are robust, relevant and timely to inform decision-making processes (NZ Transport Agency 2017b).

The Transport Agency's approach to asset management is informed by, and must comply with, the Government Policy Statement, land transport plans, regional land transport plans and regional asset management plans. Some regions may also be required to comply with specific local plans and strategies in addition to these.

The Transport Agency's State Highway Investment Proposal (SHIP) is the proposed national business case for investment in assets and activities on the state highway network for the next 10 years. It outlines the state highway funding submission through the National Land Transport Programme. SHIP is informed by several key documents including the *Government policy statement on land transport 2015/16 – 2024/25* ('the Government Policy Statement') (Ministry of Transport 2017b), Transport Agency strategic direction, the government's *Regional growth programme* (Ministry of Business, Innovation and Employment and Ministry for Primary Industries 2017), regional annual plans, the One Network Road Classification and regional land transport plan priorities and objectives.

Corridor activity management plans play a key role in the development of the SHIP through capturing a holistic view of the customer levels of service provided through state highway maintenance, operations and investment activities on each of the 30 major corridors (NZ Transport Agency 2017c).

Network outcome contracts (NOCs) for maintenance and operations activities aim to deliver greater value for money and improved customer satisfaction. These contracts are performance based and use key indicators to ensure outcomes are achieved. Contractors operating under NOCs deliver core network and asset management activities.

The One Network Road Classification also provides a framework for maintaining and operating New Zealand's road network and helps local government and the Transport Agency make better decisions based on road function.

Each level of asset management throughout the Transport Agency has specific information needs in order to develop these plans and fulfil operational and maintenance contracts.

2.3 Asset management practice

Life cycle asset management involves the planning, analysis and identification of needs, requirements and activities for the full life of the asset, from its current condition until replacement or end of life. The Transport Agency intends to develop advanced lifecycle asset management plans for each asset to ensure interventions and decision processes are based on evidence and that treatments are fit for purpose (NZ Transport Agency 2015).

Maintaining an accurate inventory of road assets is an ongoing task for the Transport Agency and other road controlling authorities (RCAs). New assets are created and old assets renewed, replaced or repaired as part of day-to-day maintenance activities.

Like any management process, there are many data inputs and analysis techniques for measuring performance to support decision making, for example identifying the timing and type of asset maintenance treatments. The assessment of assets to determine their condition, capacity or life is therefore a key input to inform the asset management process.

2.4 Network management practice

The Transport Agency is responsible for delivering a safe, efficient and resilient transport network with customer values in mind. This includes the following functions:

- optimising traffic
- ensuring safe journeys
- managing incidents
- providing real-time customer information.

To support its network management objectives, the Transport Agency operates transport operations centres (TOCs) in four of New Zealand's major cities: Auckland (in partnership with Auckland Transport), Wellington, Christchurch and Tauranga (in partnership with local government).

TOCs gather data from different sources including road sensors, closed circuit television (CCTV) cameras, traffic signals, police incident reports, customer feedback and contractor reporting to provide timely and accurate information to deliver efficient network operations. Network and journey managers rely on systems such as the Traffic Road Event Information System (TREIS) to manage and communicate the impact of planned and unplanned events in real time. Network managers also liaise with the police and contractors to intervene where necessary, for example by responding to crashes and implementing detours. TOC operators also manage the network by adjusting traffic light signals, variable speed limits, variable message signs (VMS) and ramp metering in response to changing traffic conditions.

The coordinated management of planned events (such as temporary traffic management for roadworks) or large events (such as sports fixtures or community events), is also a network management task. A customer-focused approach to temporary traffic management involves providing information to customers, as well as monitoring the operational impacts of the event, including impacts that could potentially affect the safety of road users and the public.

2.5 The role of technology in transport

The Ministry of Transport and the Transport Agency set the national strategic direction for New Zealand's road network. The primary drivers for both organisations are to improve the performance of the transport network and deliver value for money from transport investment by the Government. Technology is one area the Government has identified as having the potential to deliver improvements in safety, efficiency and environmental outcomes for transport (Ministry of Transport 2017a).

The Government Policy Statement acknowledges that responding to developments in technology is a challenge for RCAs and the Transport Agency (Ministry of Transport 2017b). Similarly, the Ministry of Transport's *Connecting New Zealand* (2011) identifies new and emerging technology as one of the big issues for transport systems.

An identified challenge is enabling transport systems to quickly adapt to take advantage of new technologies and capitalise on opportunities for the transport sector. The Government Policy Statement intends (in part) to prepare New Zealand for technology innovation, including electric autonomous vehicles and emerging 'big' data management. It also recognises that improvements in technology can make a positive contribution and there is considerable scope for innovation in the way the land transport system is delivered.

The Ministry of Transport's (2014) *Intelligent transport systems technology action plan 2014–18* also recognises improvements in the availability of real-time travel information through the greater use of global navigation satellite systems (GNSS) and smartphones. This action plan acknowledges that technology will play an increasing part in managing network access and capacity over the coming decade.

The *NZ Transport Agency position statement on intelligent transport systems* (NZ Transport Agency 2014) identifies specific investment areas for intelligent transport systems (ITS). High priority ITS investment areas that have relevance for this research include:

- mechanisms for collecting quality data about the use of the network
- better quality data to drive better operations, planning and investment
- more active network management
- mechanisms that enable the delivery of accurate information to travellers to promote smarter transport choices.

The Transport Agency has also embarked on a 'Connected Journeys' initiative whereby it is creating an environment that embraces the transport revolution though its digitalisation. The 'Connected Journeys' team are responsible for transport-related technology and systems including ITS, Mobility as a Service and innovation.

2.6 Network and asset management activity classification

Network and asset management covers a very wide range of activities, many of which overlap in terms of information needs and impacts. To assist in the identification of real-time technologies and the assessment of real-time information needs that follows, a classification scheme was developed in consultation with the research steering group and is presented in table 2.1.

Table 2.1 Network and asset management activity groupings

Activity	Description
Detecting and responding to network incidents	This activity focuses primarily on unplanned incidents occurring in an urban environment. These incidents impact on customer journeys through extended travel time and delays.
Managing planned events	This activity involves monitoring network conditions with and surrounding planned events that are subject to a traffic management plan (TMP). Priorities in managing planned events include responding to unexpected impacts on customers such as excessive delays and queuing as well as managing the safety of road users and contractors in the vicinity of the event.
Monitoring weather impacts	This activity includes monitoring current weather conditions as well as proactive forecasting to assist decision making in relation to travel conditions and customer safety. Also important for management and planning of resources to respond, particularly over long time periods or multiple shifts.
Managing hazards	This activity includes monitoring natural hazards such as slips and flooding, as well as hazards relating to the road assets themselves, for example poor road surface conditions. Timely alerts of hazards and defects are required to ensure public safety and minimise damage to assets. This activity is predominantly focused on rural roads.
Asset and site surveying	This activity involves collecting data on roads, other assets and the surrounding road environment (eg slopes) using data collection technologies and surveying methods such as unmanned aerial vehicles (UAVs) and in-vehicle or vehicle-mounted sensors. This activity focuses on one-off or occasional surveys rather than continuous monitoring methods.
Structural asset monitoring	This activity involves monitoring structural assets (bridges and tunnels) to detect critical events and identify changes to structural integrity.

Each activity includes different types of sub-tasks with varying information needs. There is also an element of overlap between the seven activity areas, for example weather monitoring and managing hazards. Some activities are also split by urban/rural focus, for example responding to unplanned incidents impacting on network efficiency is predominately an urban issue whereas monitoring weather impacts is more relevant for rural areas.

3 Literature review

The literature review explores the range of real-time technologies available for network and asset management purposes. Section 3.1 provides an overview of technologies most relevant to this research, including examples of their application within New Zealand and internationally. Weather event monitoring is discussed in more detail in section 3.2. Sections 3.3 and 3.4 discuss communications networks and the interplay of communications with sensors in the internet of things (IoT) including asset management examples. Finally, this chapter concludes with a discussion of the literature that highlights the challenges associated with implementing real-time technologies in New Zealand.

3.1 Real-time technologies and applications

A broad range of sensor technologies can collect real-time information to support asset and network management activities. Given the vast range of activities and tasks that fall under the definition of asset and network management, the literature review is not intended to be exhaustive in scope but instead focuses on those sensors considered most promising in the New Zealand context as identified through stakeholder consultation and a desktop literature scanning exercise. Known applications of each sensor are listed at the end of each sub-section below.

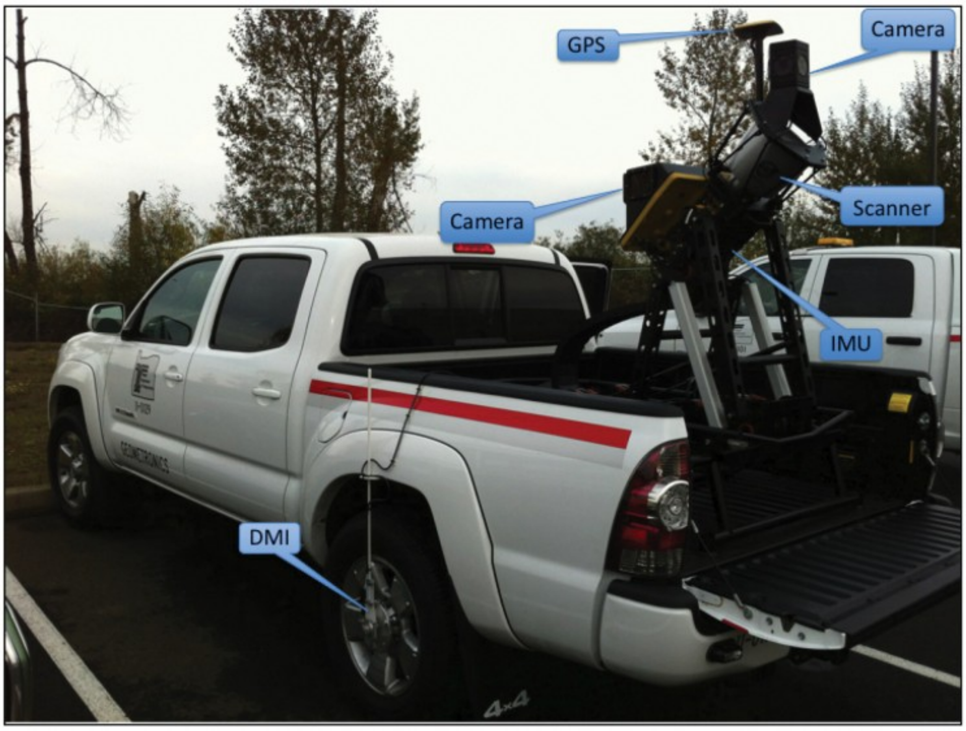
3.1.1 LIDAR

Light detection and ranging (LIDAR) is a remote sensing method that uses laser light to measure distances to a target. In three-dimensional applications, LIDAR can be used to create point clouds to develop terrain or building models. LIDAR scanning technologies include fixed, mobile and aerial applications, for example deployed on a UAV. Mobile LIDAR systems are used along navigable road corridors and these comprise the following five components, which must be integrated and calibrated:

- the mobile platform
- positioning hardware (eg GNSS and inertial measurement unit (IMU))
- 3D laser scanner(s)
- photographic/video recording
- computer and data storage.

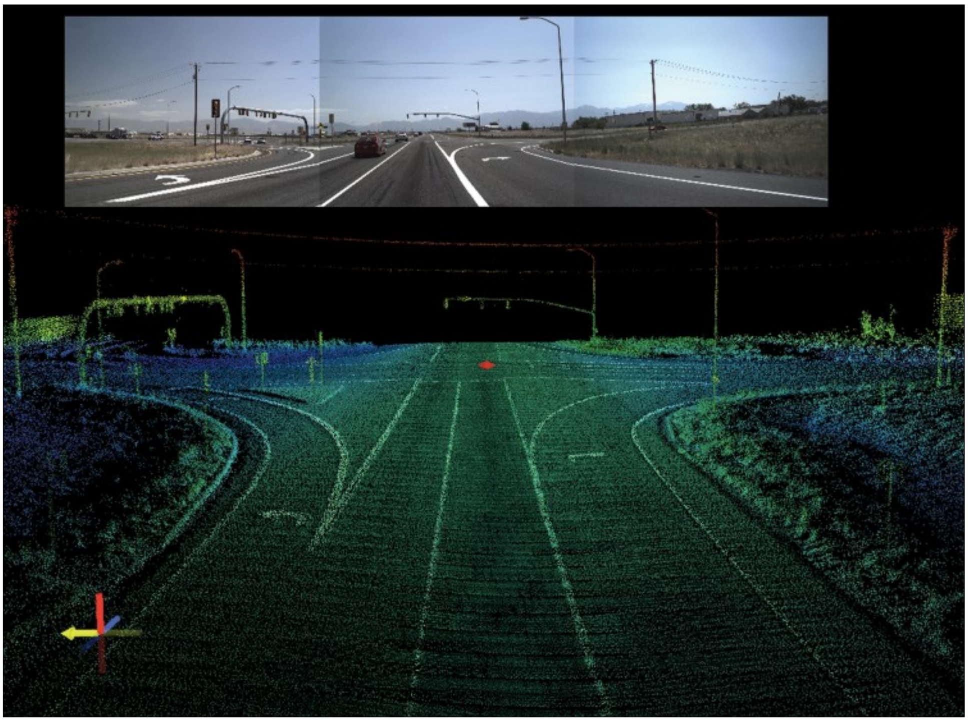
More complex mobile LIDAR systems will use multiple GPS receivers and an IMU and distance measuring instrument (DMI) for improved positioning. The GPS/IMU systems work together to continually report the best possible position. In poor satellite coverage, the IMU manages the bulk of the positioning workload. However, when satellite coverage is ideal, the IMU's positional information is then updated from the GPS (Williams et al 2015). A mobile platform connects all data collection hardware into a single system and is usually rigid as shown in figure 3.1.

Figure 3.1 Mobile LIDAR system (sourced from Williams et al 2015)



LIDAR data collected along roads can be used for multiple analyses, including stopping sight distances, adequate curve layouts, slope, drainage properties, lane width and pavement wear (Williams et al 2015). Figure 3.2 demonstrates road corridor mapping using a mobile LIDAR system.

Figure 3.2 LIDAR system used for road corridor mapping by Utah Department of Transportation (Williams et al 2015)



The use of ground-based LIDAR in New Zealand is becoming increasingly common and cost effective. UAVs for image capture without LIDAR have been adopted by some RCAs. Southland District is using them for slip monitoring, erosion monitoring and bridge inspections (McCallum 2016).

Some LIDAR technologies have the capability to deliver data in real time, although there are limited benefits in doing so for asset and network management purposes. LIDAR technologies do, however, provide significant benefits in terms of capturing a snapshot of an incident or asset at a high accuracy without lengthy field inspections or road closures.

Challenges of mobile LIDAR system include (Williams et al 2015):

- Measurements are performed from a moving platform, requiring precise GPS/IMU readings for accurate data geo-referencing.
- Sensors collecting data at high speeds and at high densities create large datasets that can be difficult to work with on standard computing platforms and software and require a substantial amount of data storage and backup during a project.

Real-time applications of LIDAR include:

- tunnel monitoring
- asset mapping and condition assessment
- maintenance inspections
- construction auditing
- monitoring unstable slopes and coastal erosion
- supporting crash investigations.

3.1.2 Fibre optics

Fibre optic technologies are used for both data collection and data transfer. The principal of fibre optic technology is based on measuring changes in light as it passes through a fibre (Fernandez-Vallejo and Lopez-Amo 2012).

Fibre optic sensors provide many benefits over other sensor types owing to their durability, stability and insensitivity to external electromagnetic disturbances and other sources of error. These sensors come in many forms and are categorised, for the purposes of this research, into interferometric sensors and distributed sensors. Table 3.1 summarises some relevant optical fibre technologies and their potential applications.

Table 3.1 Summary of fibre- optics technologies and applications

Activity		**Description**	**Potential network and asset management functions**
Interferometric sensors	Sagnac Interferometer	Measures rotation, acoustics, vibration and strain.	Real-time deformation monitoring.
	Mach-zehnder and Michelson interferometers	Detects the difference in optical path length for two light signals.	
	Fabry-Perot	Parallel reflecting surfaces at a known distance.	Smart structure monitoring, seismic application, gyroscopes for navigation purposes and chemical sensing.

Activity		Description	Potential network and asset management functions
Distributed sensors	Optical time domain reflectometry	Based on Raleigh scattering.	
	Raman optical time-domain reflectometry	Based on Raman scattering, dependent on the temperature of the fibre	Can measure temperature with a resolution of 0.2ºC. Limited to approximately 8km distance, water detection.
	Brillouin optical time domain reflectivity (BOTDR)	Based on Brillouin scattering from acoustic vibrations, can monitor over long ranges.	Measures both temperature and strain, tipping point analysis and structural health monitoring, tunnel deformation.
	Forward time division multiplexing	Measures light loss under bending of the fibre to establish magnitude and location of applied forces.	Wheel loads of moving vehicles across multiple lanes, vehicular speed, vehicle width and axle spacing.
	Distributed acoustic sensing	Longitudinal fibre optic cable to detect acoustic ‘events’ near the cable.	Incident detection and vehicle tracking. Congestion and queuing.
	Fiber Bragg grating	Change in light diffraction under deformations or variations.	Strain sensors and temperature sensing. Slope instability warning, tipping point analysis and structural health monitoring, displacement. Liquid level sensing.

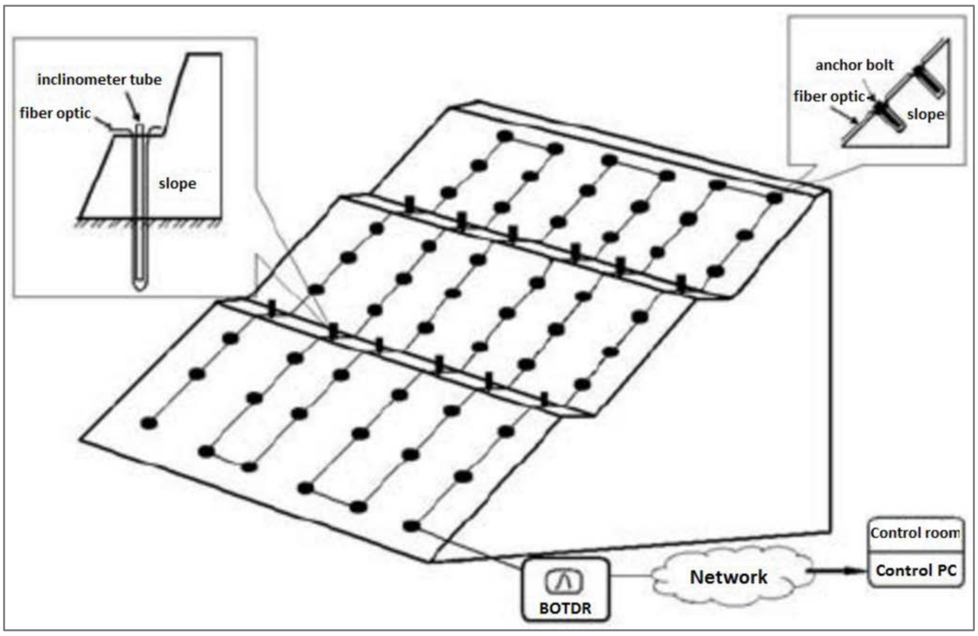
Interferometric sensors have potential in practical applications such as real-time deformation monitoring (Lee et al 2012) although their application is currently limited.

Distributed acoustic sensing has been trialled in New Zealand to detect incidents and track vehicles (Pinchen et al 2014). The ability to monitor queuing and congestion was not explicitly investigated but there is potential to extract these indicators based on the data generated. Similarly, distributed optical fibre strain sensors can be used to monitor longitudinal deformation in tunnel structures, although the application of these technologies is not yet well established in practice (Song et al 2011).

Fibre optics can be used to detect slope instability and land settlement by installing continuous fibre optic cables across a site requiring monitoring. This technology is being used in the construction of the Christchurch Northern Corridor. Buried under the ground to detect settlement during construction, this system will also be used during the operation of the road to detect vehicles (based on acoustic profiles), temperature changes (which may indicate flooding, for example) and pinpoint damage following an earthquake. The use of optical fibre is a cost-effective solution as it reduces the number of surveys required during construction.

Another example of optical fibre technology for slope stability monitoring is a BOTDR-based distributed optical fibre sensing monitoring system (figure 3.3). This system consists of a network of sensing optic fibre, BOTDR and a control PC with data processing software (Shi et al 2006).

Figure 3.3 Diagram showing BOTDR- based distributed fibre optical sensing system for slopes (Shi et al 2006)



Optical fibre systems reduce the need for physical site surveys; however, they can generate huge amounts of real-time data.

In summary, the potential applications for fibre optics are:

- slope stability monitoring
- road settlement and activity monitoring
- structural health monitoring
- incident monitoring.

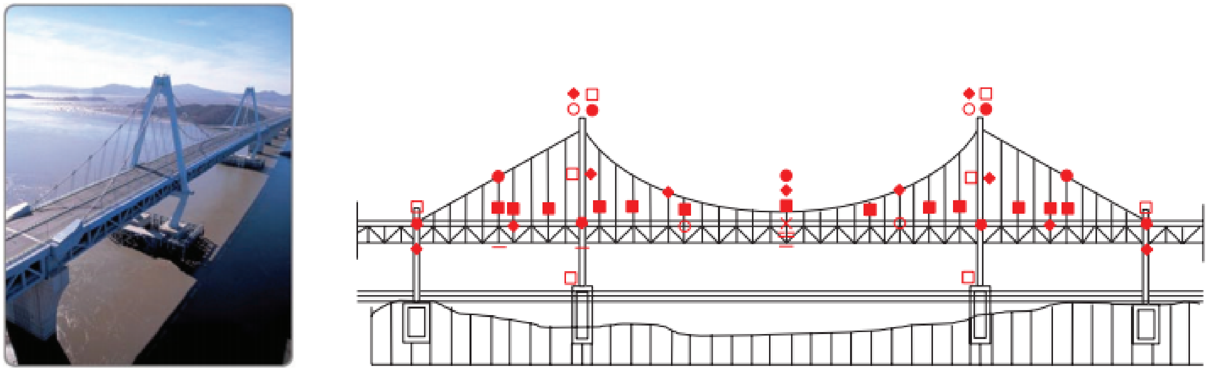
3.1.3 Accelerometers

An accelerometer is an electromechanical device that measures acceleration forces. Typically, accelerometers measure the effect that vibration has on a piezoelectric material. The piezoelectric material compresses when vibrations act upon it, releasing an electrical signal that is directly proportional to the forces acting on the structure (Couture 2013).

Accelerometers are used in structural health monitoring to detect structural damage. The key component to structural health monitoring is the development of a network of sensors that will continuously monitor the health of a structure. The system can be a permanent system that provides real-time data on how the structure is responding to loading, vibrations and environmental effects (Couture 2013).

The use of accelerometer sensors on a bridge, for example, reduces the need to close the bridge for inspection and enables understanding of bridge condition following a natural disaster. Figure 3.4 shows the locations of accelerometers (and other sensors) on the Yeong-Jong Bridge in Korea.

Figure 3.4 Bridge health monitoring using accelerometers – Yeong- Jong Bridge, Korea (Yun et al 2013



Symbol	Sensor	Number	Behavior	Symbol	Sensor	Number	Behavior
●	Thermometer	21	Cable and member	■	1D accelerometer	12	Cable
		12	Tower	□	2D accelerometer	4	Tower top and deck
:::	Static strain gage	8@4	Anchor bolt			10	Deck
		42	Deck. cross section	□	3D accelerometer	3	Tower foundation
		10@4	Anchor plate	○	Anemometer	4	Wind
		8	Link shoe	×	Laser disp. sensor	3	
—	Dynamic strain gage	76	Deck. cross section	⬟	Potentiometer	4	Expansion joint
		99	Etc.	SL	Static data logger	2	
◆	2D tiltmeter	10	Tower inclination	DL	Dynamic data logger	2	

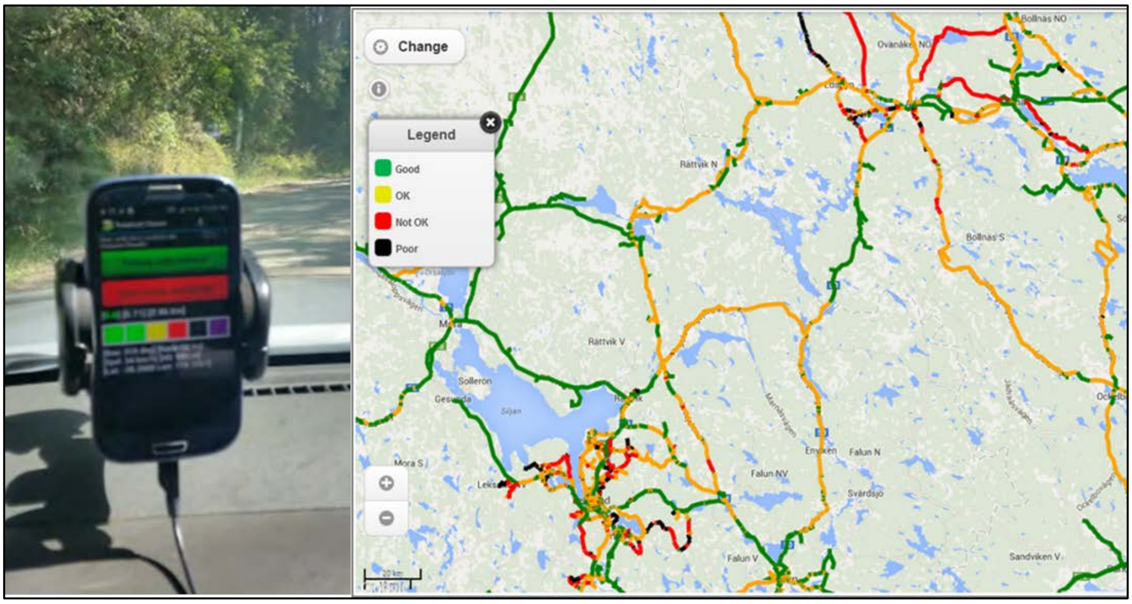
Roadroid is an in-vehicle application which uses the vibration and accelerometer sensor technology in smartphones to detect road roughness (Forslöf and Jones 2015). The output from the phone's motion sensors is an estimated International Roughness Index (IRI) score, as well as a date and time stamp, GPS position, speed and altitude. Information collected from Roadroid can be processed and mapped within two hours.

This application has been used by many RCAs in New Zealand to monitor the condition of sealed roads, unsealed roads and footpaths (Bennett 2016). A screenshot of the Roadroid application and processed data for a road network in the middle of Sweden is shown in figure 3.5.

In summary, the potential applications for accelerometers are:

- pavement condition monitoring
- bridge monitoring
- structural health monitoring.

Figure 3.5 Roadroid continuous road condition monitoring with smartphones (Forslöf 2015)

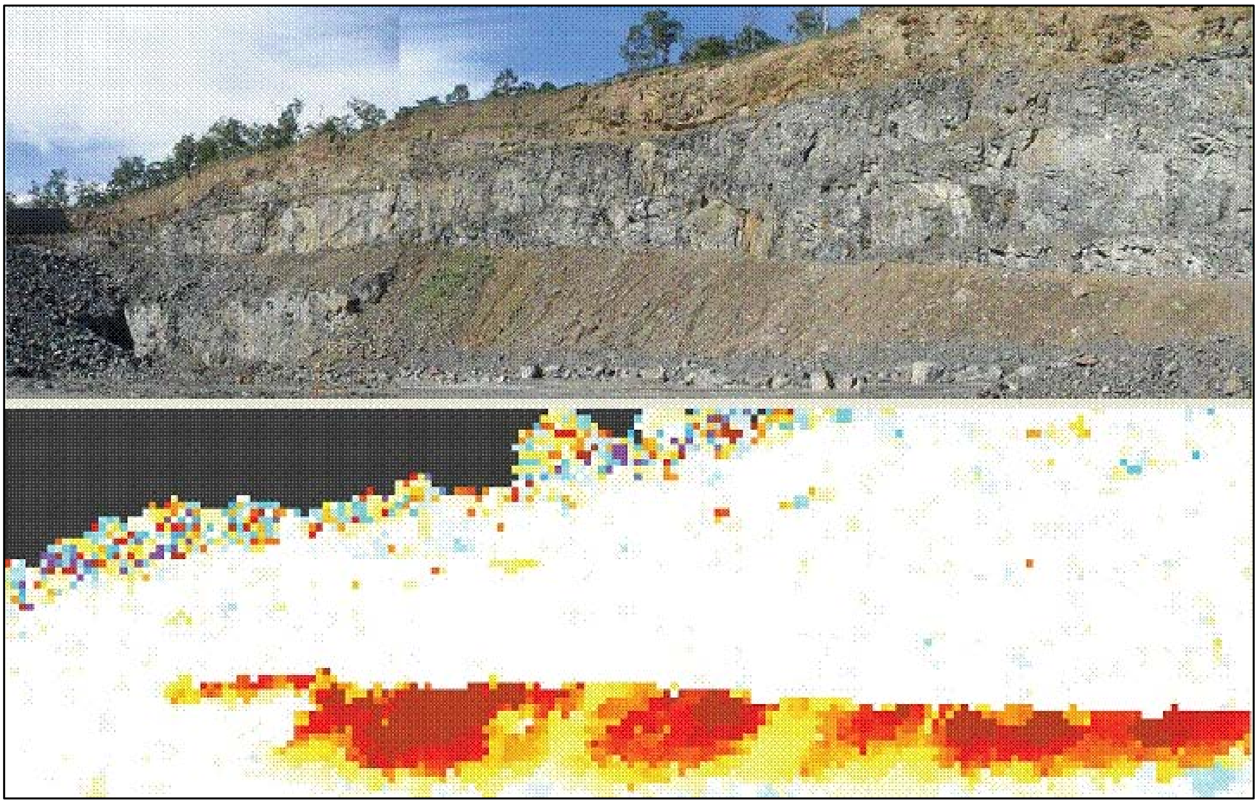


3.1.4 Radar

Ground-based interferometric synthetic aperture radar (GB-SAR) is a remote sensing method for two-dimensional monitoring of large scale surface areas and structural deformations. Providing excellent sampling frequency, high measurement accuracy and fine spatial resolution, radar is able to function in almost any light and weather conditions (McHugh and Girard nd).

Two or more radar antennas, a short distance apart, can be used to generate maps of surface deformation or digital elevation using interferometry. By comparing the phase difference in the returned signal at each antenna over time, it is possible to identify deformational or elevation change, as shown in figure 3.6. GB-SAR has been extensively deployed to study deformations of a variety of objects, including buildings, dams, bridges, towers, landslides and glaciers.

Figure 3.6 A deformation plot using synthetic aperture of the radar (Source: GroundProbe)



Radar has a very broad range of other applications, including for monitoring weather conditions (eg rain radar), river levels and traffic monitoring. Traffic monitoring relies on the ability of radar to detect changes in speed and location, enabling the measurement of vehicle speeds, queue detection and vehicle counts.

In summary, applications for radar include:

- measuring deformation of natural features (eg slopes)
- measuring deformation of manmade structures
- weather monitoring
- traffic speed
- vehicle counts.

3.1.5 Laser

Laser sensors can detect, count, trigger, map, profile, scan and verify levels, proximities and distances to practically anything (Laser Technology Inc 2017). They can be designed as through-beam sensors, retro-reflective sensors or diffuse reflection sensors.

A common application of laser sensors is in height detection systems. These systems consist of a laser detector/optical sensor, which points across the roadway at a certain height, and a method of communication to alert the driver or network managers when the vehicle detected exceeds an established height limit (figure 3.7).

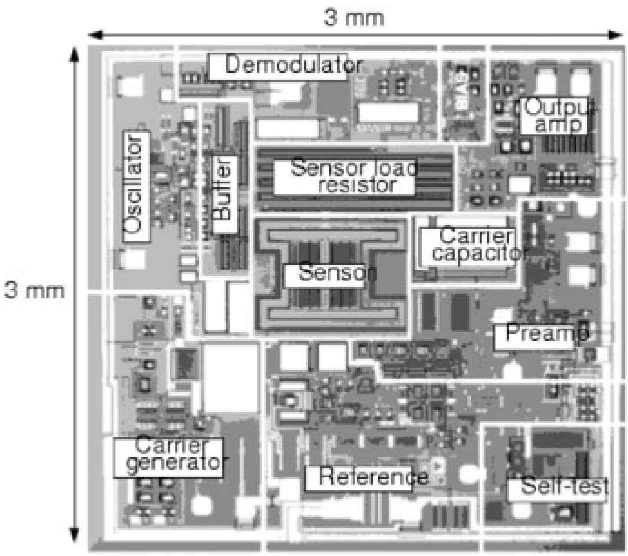
Figure 3.7 Example of a vehicle height detection system (Source: E- Squared Engineering)

Laser sensors are widely used as over-height detectors in New Zealand to warn drivers if their vehicle exceeds the maximum height for upcoming infrastructure, for example tunnel entrances, bridges and sign gantries. The Transport Agency specification ITS-08-02 sets out the minimum requirements for the supply, testing, installation and commissioning of these systems (NZ Transport Agency 2013).

3.1.6 Electromechanical sensors

Microelectromechanical systems (MEMS) integrated in a wireless network are a low cost, manageable way to monitor transportation infrastructure systems. They allow the development of 'smart' structures by embedding sensing capabilities directly into the construction material during the manufacturing and deployment process, providing autonomous structural health monitoring (Ceylan et al 2013). An example of a MEMS accelerometer, which is fabricated by advanced surface micromachining techniques, is shown in figure 3.8.

Figure 3.8 Micromachined MEMS accelerometer (Source: Xue et al 2008)



Advancements in MEMS technology and wireless sensor networks provide opportunities for long-term, continuous, real-time structural health monitoring of pavements and bridges at low cost within the context of sustainable infrastructure systems. They are an improvement over existing sensing methods, with improved system reliability, improved longevity and enhanced system performance, improved safety against natural hazards and vibrations, and a reduction in life cycle cost in both operating and maintaining infrastructure (Ceylan et al 2013).

MEMS have a wide range of potential applications. Some of these applications include:

- pavement monitoring
- temperature monitoring and concrete strength estimation
- moisture/humidity monitoring
- bridge and highway safety monitoring (MEMS accelerometer)
- monitor load condition and/or measure strain/stress information of pavements and bridges
- rust inducing salt monitoring
- corrosion monitoring
- roadside air quality monitoring.

3.1.7 Water level gauges

Hydrometric data (water level and river flow) can be captured in real time from sensors at water gauging stations at river, lake and tidal locations. This data is used by RCAs and regional councils in New Zealand to monitor water levels of rivers, streams and culverts. The real-time benefit of these systems is used to inform decision-making processes during weather events or forecasted heavy rain periods.

Water level data can be transmitted in real time via radio or mobile communications. An example of a water monitoring system is shown in figure 3.9.

Figure 3.9 Water monitoring, Rees River (Source: NIWA)

In summary, the applications for water level gauges include:

- flood monitoring
- river monitoring.

3.1.8 Weigh-in-motion

Weigh-in-motion (WiM) devices are installed on the carriageway surface of a road and measure the weight of each axle as a vehicle travels over it. WiM collects traffic data such as vehicle speed, volume, axle counts, axle weights and vehicle length data. Because WiM collects data as vehicles move across it, it could be considered a real-time technology (Smith et al 2014).

The primary use of WiM in New Zealand is to monitor impacts on assets (eg bridges) and for compliance. At the time of writing, there are nine WiM sites across the New Zealand state highway network. Some sites also have a camera for automated number plate recognition (ANPR) that enables the Transport Agency to alert freight companies whose vehicles are overloaded. This data is currently not used in real time, although there is a trial underway (the 'weigh right trial') testing the use of WiM to detect overweight vehicles and direct them to a weigh station for further inspection (NZ Transport Agency 2017d).

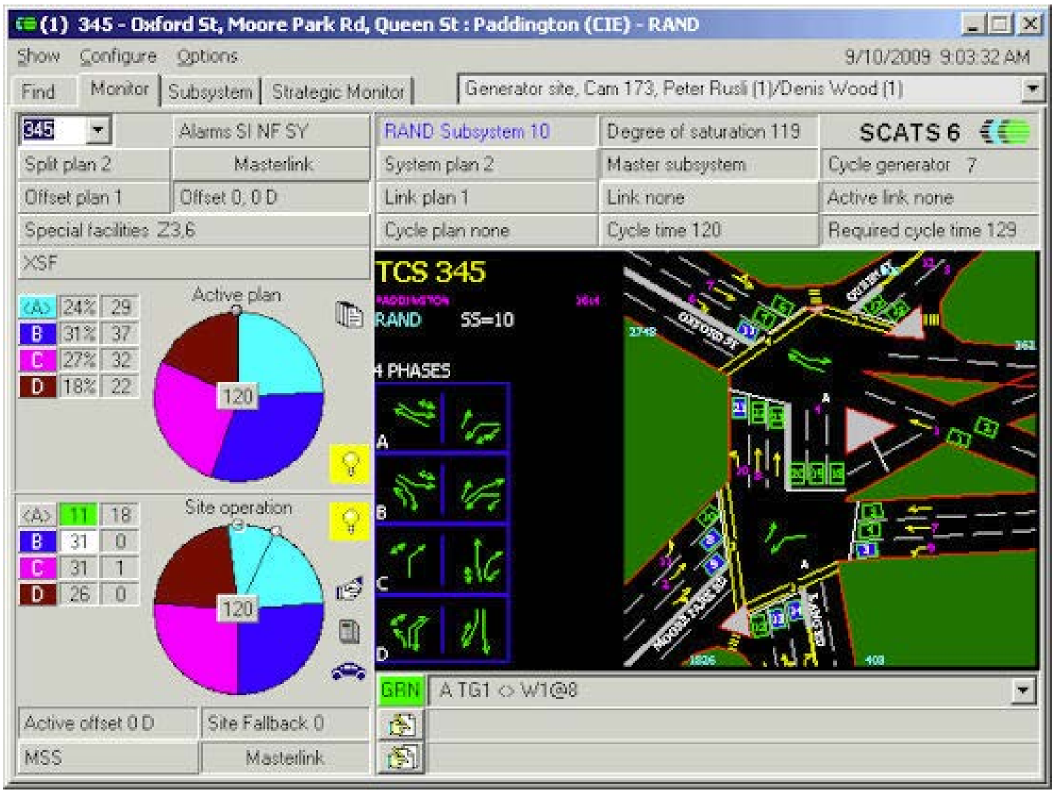
3.1.9 Sydney coordinated adaptive traffic system

Sydney Coordinated Adaptive Traffic System (SCATS) is an urban traffic management system that synchronises traffic signals to optimise traffic flow on an area basis. It considers all aspects of traffic control and can respond to demand on the network in real time by adjusting cycle times, phasing and splits at each traffic signal cycle.

Because SCATS is adaptive it is able to cope with unpredictable traffic conditions. Using logic and algorithms to analyse real-time traffic data from vehicle detectors, SCATs can adapt signal timings to deal with the prevailing traffic conditions to maximise flow and minimise delay (NSW Government 2017).

SCATS is widely used in New Zealand and can be integrated with a wide variety of ITS applications. The responsibility for managing these systems on a day-to-day basis lies with the TOCs. An example of the SCATS live action screen shot is shown in figure 3.10.

Figure 3.10 SCATS live intersection and coordination example



In summary, applications of SCATs include:

- travel time and traffic flow management
- congestion management
- event management.

3.1.10 Closed circuit television and video analytics

CCTV cameras and advanced video image detection systems are relatively inexpensive technologies for monitoring movement (figure 3.11).

Figure 3.11 Examples of CCTV cameras (source: Auto Express and Axis Communications)

Video analytics systems utilise machine vision technology to compile and analyse traffic data collected with CCTV systems. Analytic capabilities include automatic motorway condition monitoring, speed analysis, vehicle counts and classification. There are many benefits to CCTV deployment including the ability to 'see' commercial vehicle traffic on remote roadways, on major thoroughfares, or any location that can be viewed from public rights of way.

Video analytic techniques can automatically identify and count objects from CCTV in real time. This includes generating alerts when an unexpected object or behaviour is detected, for example vehicles travelling the wrong way or pedestrians on a restricted road.

CCTV video analysis is undertaken in New Zealand. Examples include the Wellington Smart Cities project (NEC Corporation 2016) and traffic monitoring across Auckland (Hewlett Packard 2016). These applications use existing CCTV networks to count and classify road users and detect traffic violations and congestion. CCTV is also used for ANPR and vehicle classification (eg motorcycle, car, truck or bus) on toll roads.

CCTV is also being applied in conjunction with rockfall detection systems to provide coverage of at-risk sites along the Kaikoura coast. This gives the ability to assess sites following activation of the system instead of deploying personnel to visit the site.

In summary, the applications for CCTV and video analytics include:

- tunnel monitoring
- traffic management
- incident detection
- data collection (volume, speed and occupancy)

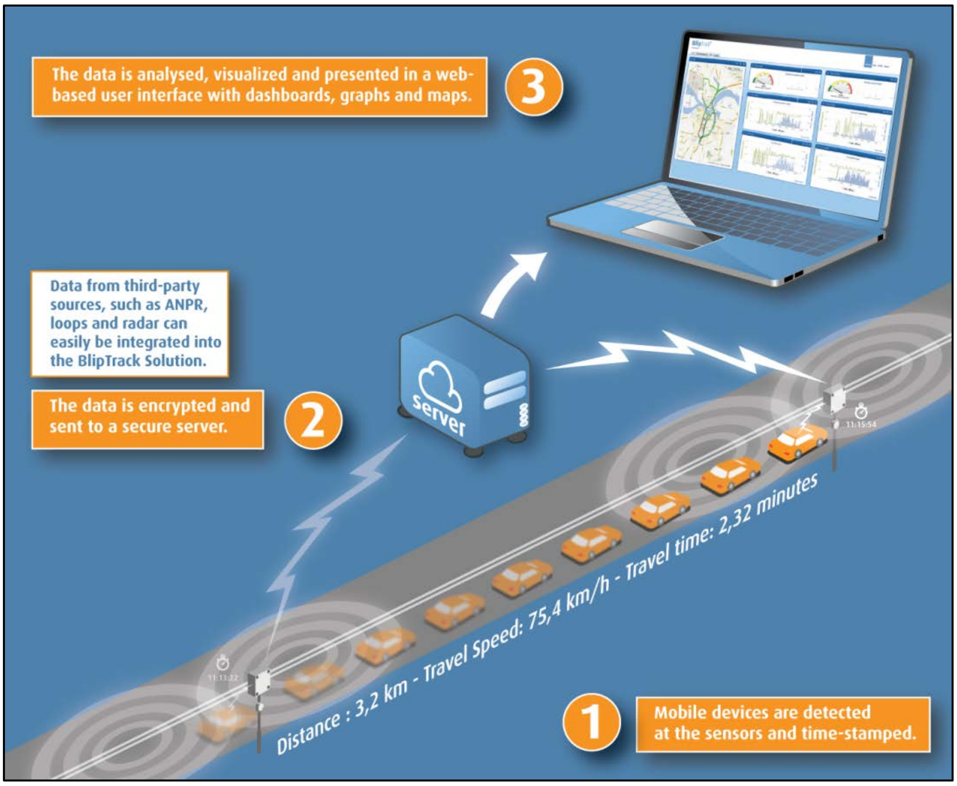
- rockfall detection
- motion detection.

3.1.11 Bluetooth and Wifi detection

Bluetooth technology wirelessly transmits data over short distances via shortwave radio. The technology is found in a variety of devices including mobile phones, wireless hands-free communication systems and computers. Each Bluetooth device has a unique identifier known as a media access control (MAC) address. Bluetooth detectors placed at the roadside can detect Bluetooth devices in passing vehicles as far as 100m away. Bluetooth sensors can be installed at key locations along the road network and detect MAC addresses of Bluetooth devices inside private, public and commercial vehicles as they travel past. Each time a MAC address is detected and matched, data on the time and location of each device is recorded, providing a measure of travel time and speed (Smith et al 2014).

Bluetooth detection systems are used across New Zealand primarily to monitor travel times between fixed locations (figure 3.13). Most Bluetooth detection devices are permanent installations, although temporary installations are being used by contractors to monitor travel times for planned events including roadworks and temporary events.

Figure 3.13 Example of BlipTrack Bluetooth and Wifi detector (Source: Blip Systems)



Bluetooth detection systems in New Zealand cover much of the state highway network as well as an extensive Auckland network and urban installations in Nelson, Christchurch and Queenstown. The Transport Agency uses Bluetooth to measure delays during construction projects, travel time savings following road upgrades and traffic optimisation such as the SMART motorway scheme.

Devices with the ability to sense both Bluetooth and Wifi significantly increase sample rates, by being able to capture mobile devices in areas with slow moving traffic, or to capture bicycles and pedestrians (Blip systems 2017).

Information derived from Bluetooth detection technologies is used by TOCs and travel times are reported to the public through VMS and websites such as DriveLive (www.drivelive.nz). DriveLive displays current journey times derived from the Bluetooth network, including delay (compared with free-flow conditions) and an indication of whether conditions are improving or getting worse (Beca 2017).

Addinsight is a Bluetooth-based system developed in Australia that also monitors travel times; however, this system also uses self-learning and complex data mining techniques to identify abnormal conditions and predict travel times. Addinsight also uses Bluetooth sensors as broadcast beacons. In combination with a smartphone application, motorists can receive alerts on upcoming incidents and delays. This can be managed automatically when the system automatically identifies abnormal conditions, or manually through the TOC.

In summary, applications for Bluetooth and Wifi sensing include:

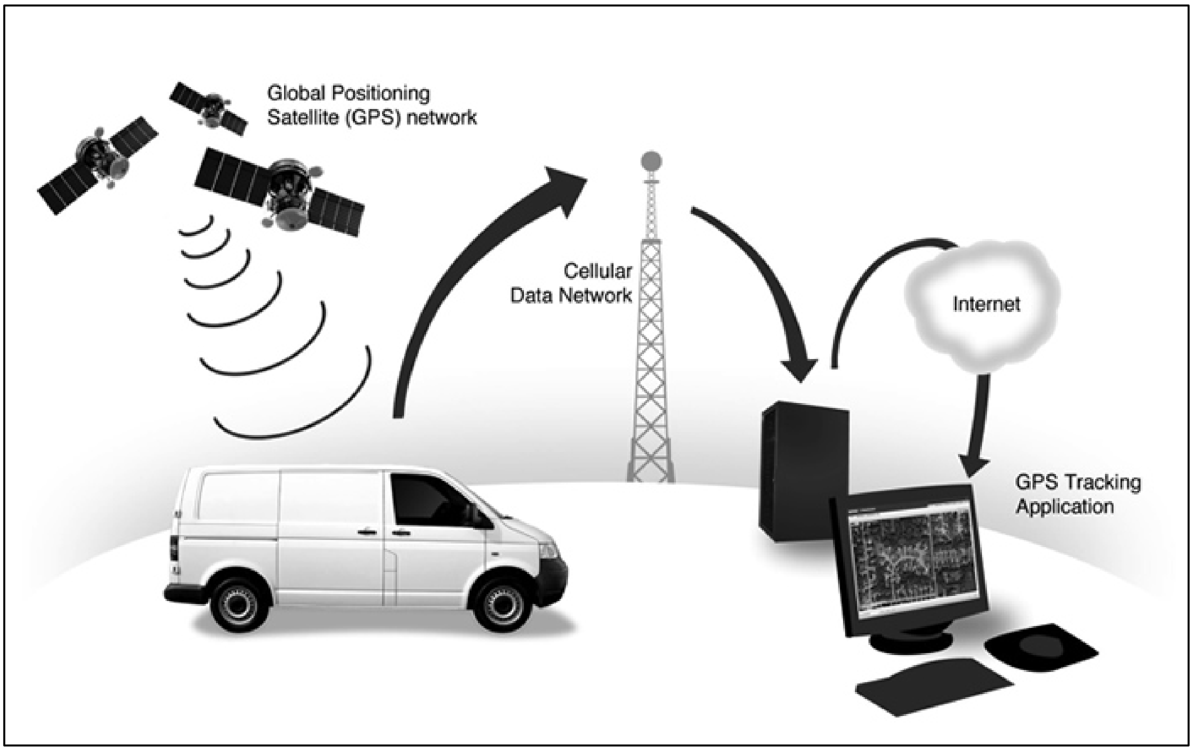
- travel time and speed monitoring
- congestion, queuing and travel time reliability
- traffic information broadcast.

3.1.12 Global navigation satellite systems

GNSS use satellite constellations and ground-based receivers to provide autonomous geo-spatial positioning with global coverage. While it is technically correct to use the term ‘GNSS’ to refer to positional information provided from satellite-based systems, the term ‘GPS’ has been used in this report to recognise the ubiquity term such as ‘GPS in-car navigation’ in common language.

GPS requires a clear view of the sky to find the location, with horizontal accuracy in optional conditions in the range of up to 3m. GPS technology can continuously gather location and timestamp data to produce a dataset tracking the movements of the receiver. In ITS applications, a receiver can be installed onto a vehicle as either a standalone system or as part of the GPS navigation system, providing a full history of a vehicle’s travel movements. Data collected by GPS receivers can be uploaded to a central server using a mobile connection or may be retrieved on a regular and near real-time basis as shown in figure 3.14 (Smith et al 2014).

Figure 3.14 GPS vehicle tracking (Source: PureConnectGPS)



GPS location data from moving vehicles is collected from a range of sources across New Zealand, including commercial fleets and private vehicle users.

GPS data collected from probe vehicles using services including Google and fleet management services, such as EROAD, can provide vehicle speed and travel time information. To protect the privacy of individual vehicles and users, only aggregated data from these sources is shared with third parties such as TOCs and the public.

One application using real-time GPS data was recently trialled with Fulton Hogan to evaluate whether real-time data sources could accurately measure disruption to road users caused by roadworks and other incidents (Ward 2017). The application was developed to enable proactive delay and queue mitigation through real-time alerts, detection of abnormal congestion, and identification of the exact location of an incident on the network. This product helps to optimise operational costs, intuitively assists with traffic management through detecting and locating abnormal congestion and unpredicted traffic flows, and minimises disruption for road users (ibid).

GPS technology is also used for fleet management purposes to calculate road user charges and to track and manage the location of vehicles within a fleet. This information is available, historically, from one vendor to the Transport Agency for network analytics and there is an opportunity to explore other uses of this data to inform network and asset management tasks.

In summary, applications for GPS technology include:

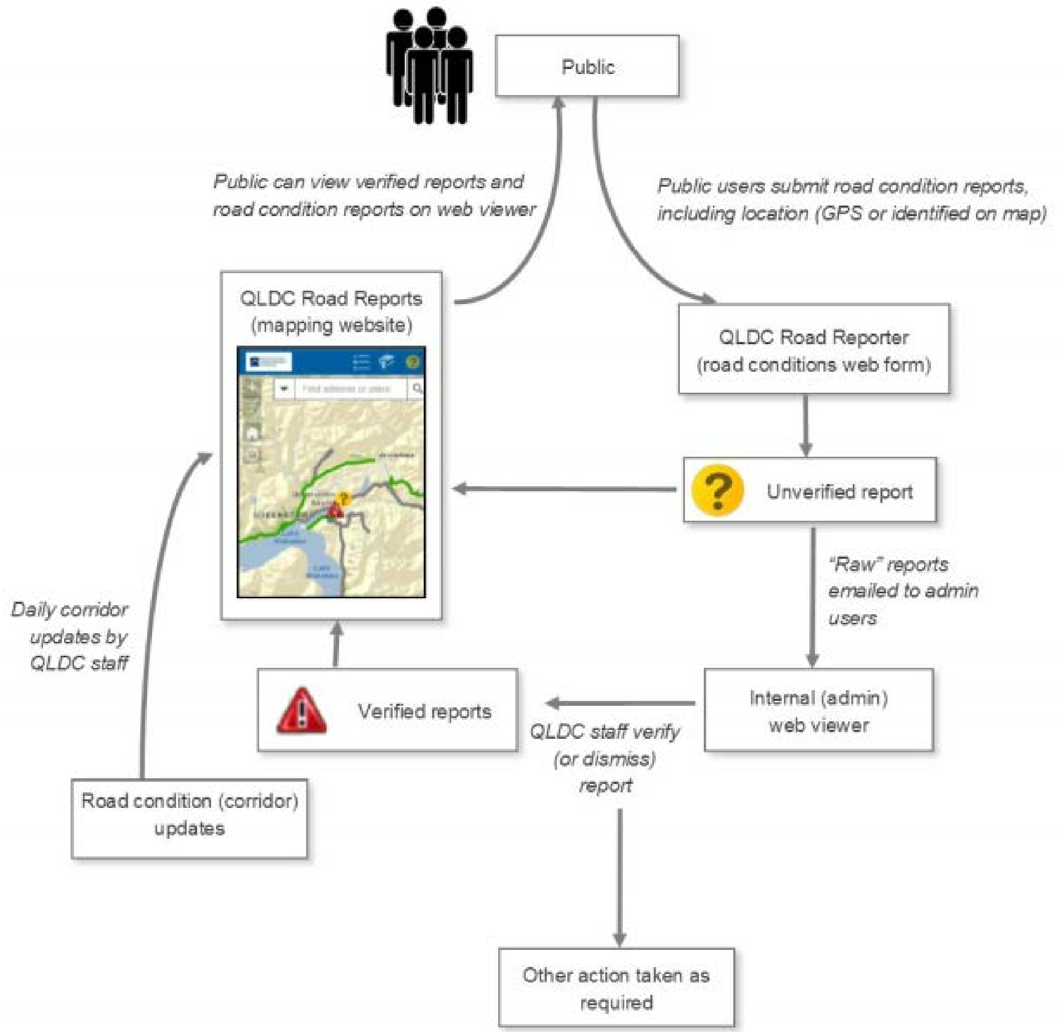
- travel time and speed monitoring
- measuring congestion, queuing and travel time reliability.

3.1.13 Crowdsourcing

Crowdsourcing is the practice of engaging the services of a large and undefined group of people to provide information or input into a particular task or activity that would otherwise be too difficult or impossible to solve using traditional outsourcing or data collection methods (Harris et al 2016).

In transport applications, crowdsourcing for data collection relies on the use of mobile devices (eg smartphones) acting as sensors to 'fill a gap' where traditional traffic monitoring sensors do not exist, or cannot report in real time. Crowdsourcing provides a relatively low-cost method for collecting transport data, using human inputs rather than, or alongside, specialised sensory equipment to fill an information gap. Crowdsourced data can sit alongside traditional transport data sources to help with verification or to provide additional context (Harris et al 2016). Figure 3.15 provides an overview of a web application developed in New Zealand to collect, verify and display crowdsourced road reports (ibid).

Figure 3.15 Crowdsourcing web application framework



Crowdsourced data can be collected in several ways, including custom-developed applications or through data sharing arrangements with third party applications. Waze is a popular global community-based crowdsourcing application where users can directly report events such as crashes, speed cameras, congestion and flooding through an application interface. Vehicle speed and location data is also collected and the potential for integrating Waze data into traffic operations management has been explored by a number of road agencies, including the Florida Department of Transportation (Harris et al 2016). Under a two-way data sharing agreement, each party provides information through a customer-to-customer plug-in connection.

The applications of real-time crowdsourced data for supporting traveller information and network efficiency in New Zealand with the most potential are (Harris et al 2016):

- public transport service occupancy and capacity
- congestion and travel time reporting
- monitoring temporary planned or unplanned events
- incident and hazard reporting.

3.1.14 Vehicle-to-vehicle and vehicle-to-infrastructure technologies and autonomous vehicles

Autonomous vehicles and the interactions between them (vehicle-to-vehicle or V2V) and the road environment (vehicle-to-infrastructure or V2I) is an emerging technology that has the potential to yield vast amounts of data that could feed into network and asset management activities.

While V2V technologies are not currently available in New Zealand, V2I technologies are imminent and worthy of further discussion. Baskar et al (2011) outline three levels of interaction related to how infrastructure can communicate with intelligent vehicles:

- Infrastructure-supported systems provide information to support intelligent vehicles' decision-making processes.
- Infrastructure-managed systems provide instructions to intelligent vehicles to make a manoeuvre, eg exit from and entry to the road system.
- Infrastructure-controlled systems take full control of the intelligent vehicle based on optimising traffic flows and other traffic management purposes.

Enabling cooperation and coordination between vehicles and roadside infrastructure can reduce congestion and environmental impacts and improve network performance (Basker et al 2011). Real-time traffic models can improve road network utilisation supporting ramp metering, traffic signal optimisation and lane management.

Cooperative intelligent transport systems use dedicated short-range communications to transmit information both between vehicles and between vehicles and infrastructure. This increases the quality and reliability of information available to drivers about their immediate environment, other vehicles and road users by providing information that may not be directly visible, for example alerting drivers to a potential collision, poor weather conditions or congestion.

Autonomous and connected vehicles use V2V and V2I technologies, along with advanced in-built sensor systems to enable these vehicles to safely navigate roads with minimal driver oversight. The data collected by these vehicles can potentially be used for a wide range of applications outside driving the vehicle, for example sensors such as radar, LIDAR and image detection could detect potholes and automatically report these to RCAs.

At this time, there is uncertainty around how and when autonomous vehicles will be deployed, and the infrastructure required to support them in New Zealand. It is also difficult to predict how real-time data generated by these vehicles will be used and shared in the future.

3.1.15 Other sensor technologies

This literature review is not an exhaustive list of technologies. Other technologies that may be used in network and asset management but are not addressed in greater detail include:

- fog, smoke and fire detection
- sound detection
- light detection
- traditional traffic monitoring sensors such as tubes and loops
- piezoelectric sensors
- tilt and trip sensors
- environmental sensors (eg air and water quality monitoring).

3.2 Weather monitoring

Weather monitoring involves using a range of sensors and systems to detect changing conditions at both a macro-level (eg atmospheric conditions) and micro-level (eg road surface temperature). This information supports road weather forecasting.

Road weather information systems consist of weather stations in the field collecting data, a communication system for data transfer, and central systems to collect field data from numerous weather stations. These stations combine multiple sensors to collect a range of information and meteorological data including air temperature, relative humidity, wind speed and direction, precipitation and visibility.

The MetService's roadside weather network includes over 50 dedicated road weather stations recording atmospheric conditions (figure 3.16). Some sites include sensors in the road surface which collect information such as road surface temperature, water film, freezing point and the presence of de-icing agent. This information is updated and transmitted every minute for most sites.

Figure 3.16 Roadside weather station near Porters Pass, State Highway 73 (source: authors)

The MetService reports real-time weather and road conditions to the Transport Agency including measuring wind, air temperature, humidity, rainfall, water film on roads, chemicals and freezing points. This information is used to inform road users of road conditions and closures. It can also be used by contractors to determine whether conditions are suitable for maintenance operations such as road marking and road surfacing.

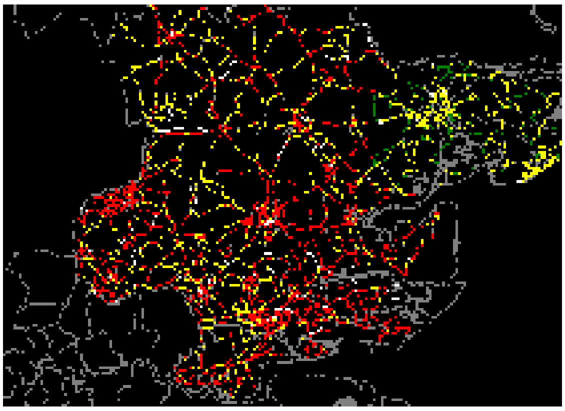
In addition to general road condition reporting and forecasting, weather monitoring is used for a range of other applications in New Zealand. These are discussed in more detail below.

3.2.1 Thermal mapping

Thermal mapping models the variability of road surface temperature on a road network in relation to weather conditions. The Transport Agency commissioned a national thermal mapping system in 2011. The system is operated by MetConnect and Vaisala using weather stations installed along the highway network (NZ Transport Agency 2012). The technology provides 24-hour predictions of road surface temperatures across the state highway network.

Thermal mapping is an integral part of an ice prediction system. Through understanding the profile of minimum road surface temperatures across a network, specialists can predict if, when and where ice is likely to form on the road network. This allows better forecasting of road conditions for decision makers, with likely positive safety outcomes. Real-time thermal mapping complements forecasting through up-to-the-minute real-time mapping of road temperature information (figure 3.17). Where the forecast and observed data deviate from one another, real-time thermal maps identify areas of the network that may require treatment ahead of the original schedule (Vaisala 2017).

Figure 3.17 Time step thermal map (Source: Vaisala)



3.2.2 Weather-activated speed management

Weather activated variable speed limits (WAVSL) manage speeds by temporarily reducing the speed limit to suit the weather conditions.

WAVSL has been trialled on State Highway 29 across the Kaimai Ranges as part of a strategy to reduce the number and severity of crashes occurring on this section of road during adverse weather conditions. A weather station located near the summit uses sensors to monitor rain, wind, ice, surface water and visibility. This data is transmitted to the Auckland TOC at one-minute intervals and when pre-determined weather criteria are met an alarm is activated. A TOC manager can then monitor conditions via CCTV to ensure the alert is correct and apply an appropriate speed limit (Crean 2016).

Figure 3.18 WAVSL trial in operation (Crean 2016)

3.2.3 Avalanche control

To keep the Milford Road safe and open as much as possible during the avalanche season, the Transport Agency operates an avalanche control programme that predicts and controls avalanches. This system uses specialised weather and condition monitoring including snow pit studies, current weather data (from automated road and high-level weather stations), the weather forecast and local knowledge of avalanche activity. Data is obtained from equipment based both at road level and on the mountain, and is monitoring continuously to maximise the safety and availability of the road (NZ Transport Agency 2017a).

3.3 Communication networks

Real-time technologies rely on communications networks to provide timely and reliable transmission of data. These networks include:

- cable networks
- radio frequency networks
- satellite
- mobile networks
- low powered wide area networks.

Cable networks, including fibre optic networks, are widely used in urban areas and motorways for collecting, communicating and controlling ITS assets. ITS applications can also use radio frequency networks for communicating over short and long distances.

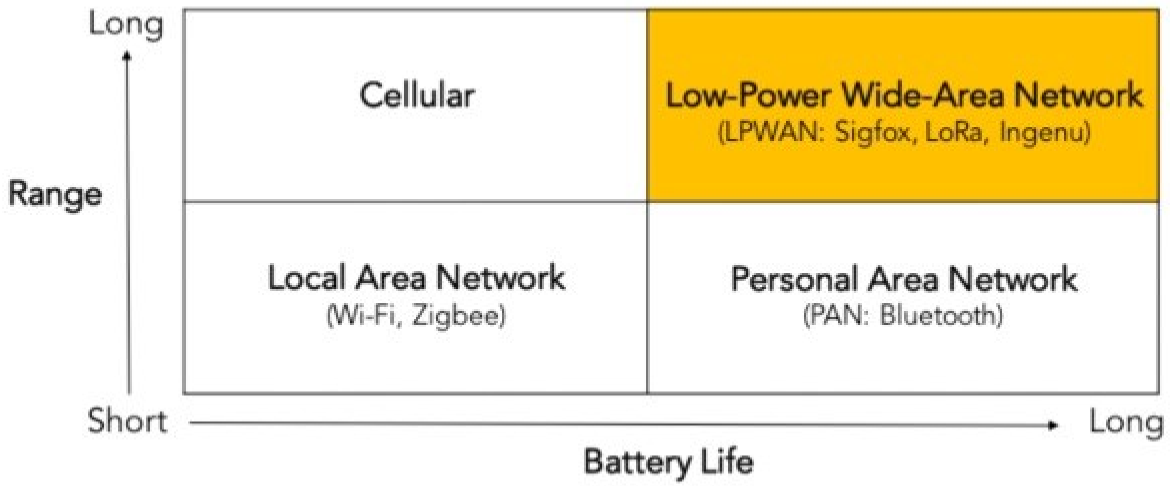
Satellite communications are used in remote locations, including weather stations and by contractors, where other methods of communication are unavailable. Satellite networks are more expensive to use compared with other types of communication and therefore tend to be used sparingly in New Zealand.

New Zealand currently has mobile coverage for over 95% of where people live and work, but this represents only 50% geographic coverage (Ministry of Business, Innovation and Employment 2017). This coverage includes 2G, 3G and 4G networks with each new generation offering improved speed and performance. It is anticipated that 5G will become available in the early 2020s (New Zealand IoT Alliance 2017).

Areas with low or sparse populations have poorer quality or non-existent mobile connectivity. This includes much of the rural state highway network. The government is currently funding an expansion of mobile coverage through the Mobile Black Spot Fund targeting main highways and key tourist hotspots (Crown Fibre Holdings 2017a). This includes locations such as the alpine passes, the West Coast and Milford Sound.

Low power, wide area networks (LPWANs) are an emerging platform that supports IoT (see section 3.4) devices by enabling the communication of small packets of data over large area networks. Compared with mobile networks, LPWAN-enabled devices have a longer battery life, greater range and are cheaper to set up and maintain. LPWANs come in many different forms, including LoRaWAN and Narrowband-IoT (NB-IoT) (figure 3.19). Mobile networks, however, have the advantage of transmitting larger packets of data such as image, video and audio files.

Figure 3.19 Comparison of LPWAN with other wireless networks (source: KotahiNet 2017)



Four companies in New Zealand are actively rolling out LPWAN in New Zealand (table 3.2). The increasing coverage of LPWAN and mobile networks presents an opportunity to expand the possible applications of real-time technologies throughout the country. LPWAN enables assets to be monitored in real time where previously the cost and accessibility of power sources and communications networks were prohibitive.

Table 3.2 LPWAN networks in New Zealand

Company	LPWAN Type	Coverage
Thinxstra	Sigfox LPWA	Aims to have 95% population coverage by the end of 2017 (KotahiNet 2017).
KotahiNet	LoRaWAN	Aims to complete national coverage. Already have coverage over 75% of the population (Thinxtra 2017).
Vodafone	NB-IoT	Deployment underway early 2017.
Spark	LoRaWAN	Deployment underway early 2017.

A current challenge, however, is the plethora of LPWAN and mobile options and protocols available (New Zealand IoT Alliance 2017). While it is expected this market will become clearer in the long term, there are concerns this will inhibit the adoption and use of these networks in the short term (ibid). A related challenge is change in communication technologies that affects devices relying on older versions, for example the ongoing shut-down of 2G mobile networks across New Zealand as demand for 3G and 4G networks increase.

3.4 Internet of things

IoT refers to networks of interconnected and uniquely identifiable devices embedded in physical objects. These devices include sensors and communication systems as discussed in sections 3.1 and 3.3. Being able to connect almost any object to a wider network that includes data collection, transmission and analytical components presents new opportunities for managing assets and road networks.

The IoT opportunity for New Zealand was assessed by New Zealand IoT Alliance (2017) as potentially delivering $2.2 billion in benefits over 10 years with the greatest share of benefits being in the transport and logistics sector ($556 million benefits).

In the context of road assets and structures, IoT sensors can be used to monitor the condition of an asset, including whether the asset has moved or tilted and whether it is idle or in use. The location, speed and path of mobile assets can also be monitored. IoT can be deployed to monitor hazards and environmental conditions that could affect, or are a result of, the operation of the transport network.

The emergence of IoT is being driven by improved data collection and communication capabilities including cloud computing and improving mobile and wireless networks (Merswolke 2013). Further advances are inevitable with the emergence of connected and autonomous vehicles that are being trialled and tested in New Zealand and internationally.

3.5 Real-time technology challenges

This section discusses some of the challenges associated with the use of real-time sensors and technologies. A number of these challenges have already been covered in the literature review.

3.5.1 Data quality and coverage

The application of real-time data must satisfactorily address issues relating to quality, coverage and compatibility. Transport authorities will need to ensure an adequate level of data auditing and literacy to understand and effectively use the real-time streams of data. The emergence of technology-driven big data in transport is still susceptible to traditional data problems relating to statistical validity, sample bias, sample error or incorrect imputed causality. A comprehensive understanding of data provenance is required to avoid drawing false or inaccurate conclusions (International Transport Forum 2015).

Poor quality data or data that has incomplete coverage may require further processing but should not necessarily be excluded from further consideration if there is potential value in that data and sufficient metadata can be supplied. Any limitations or assumptions, however, should be carefully stated (Smith et al 2014).

3.5.2 Privacy

Merging sensor-collected and crowdsourced data generates new knowledge about the transport network, activity flows, asset and weather conditions. It also creates unique privacy implications. The location and movement data can potentially reveal patterns of activity that could be linked to individuals, creating opportunities for misuse (International Transport Forum 2015).

When considering the role of crowdsourced data in transport applications, Harris et al (2016) found the principles of the Privacy Act 1993 do not restrict the collection of crowdsourced data, provided the privacy of data collection is considered or assessed at the outset of the project. The Privacy Commissioner (2009) also provides additional guidance on the appropriate use of CCTV to ensure compliance with the Privacy Act 1993.

3.5.3 Third-party data and partnerships

A large amount of real-time data is held by the private sector. Access to this data by public agencies may not fit traditional supplier-client relationships and requires innovative public-private data sharing agreements (International Transport Forum 2015). Smith et al (2014) investigated risk management and business case development for the procurement of emerging digital data sources. Identified actions that support public-private data agreements include:

- early and ongoing engagement with suppliers
- a flexible approach to contractual dealings, particularly during initial phases
- short-term contracts (where possible) to allow flexibility to fine-tune the specifications of the data stream initially
- ensuring the Transport Agency is not overly constrained in the use of the data.

4 Stakeholder consultation

The research team consulted with key stakeholders including industry experts, technology professionals and vendors during February and March 2017. The purpose of the stakeholder consultation was to:

- understand stakeholder information needs and current applications of real-time technologies to network and asset management activities
- identify emerging technologies and initiatives and understand the extent to which these emerging technologies provide opportunities to support network and asset management activities.

Where possible, stakeholder interviews were carried out in person across Auckland, Wellington and Christchurch, otherwise interviews were conducted via telephone or email exchange. Multiple interviews were held with some stakeholder organisations to receive a cross-section of views across the breadth of the organisation.

The stakeholders and groups who provided feedback through the stakeholder engagement included:

- a consensus view from the Transport Agency journey managers
- a workshop to discuss the views of the Transport Agency maintenance contract managers
- a consensus view from the Transport Agency asset integrators
- a representative from the Christchurch TOC
- a representative from the Institute of Public Works Engineering, Australasia
- email feedback from local government roading managers arranged through Local Government NZ
- individual interviews with stakeholders from technology firms.

The Ministry of Transport, KiwiRail and Environment Canterbury were also contacted but were unable to participate.

The participants were presented with the wider objectives of the research project as well as the agreed definition of network and asset management activities as outlined in chapter 2 of this report. Specific questions presented to stakeholders were tailored to their areas of expertise but generally included the following:

- How do you currently measure network and/or asset performance?
- How critical is receiving timely, accurate information about network and asset performance measures?
- What are the other measures of success/value in measuring network and asset management performance?
- What real-time initiatives are you aware of that provide information about network and/or asset performance?
- What technologies or datasets do you use, or are aware of that are used in New Zealand or internationally for network and/or asset management?
- What are the risks of reliance on real-time datasets?
- Are you aware of any constraints/limitations associated with introducing real-time data technology solutions?
- If money was of no concern – how would you improve network and asset performance?

- Are there any rule or policy changes that would enable more efficient network and asset management?
- What are the critical interagency connections, including government agencies and contractors, and do these impact on the potential transfer of information and information needs?
- What real-time information sources do other agencies use which may be beneficial for asset and network management activities in the transport sector?

This chapter summarises the key findings and learnings from the stakeholder consultation. The responses from stakeholders have been anonymised and aggregated, although specific industry or sector examples have been used on occasion to illustrate differences of opinion between groups of respondents.

4.1 Key findings

4.1.1 Use of real-time technologies

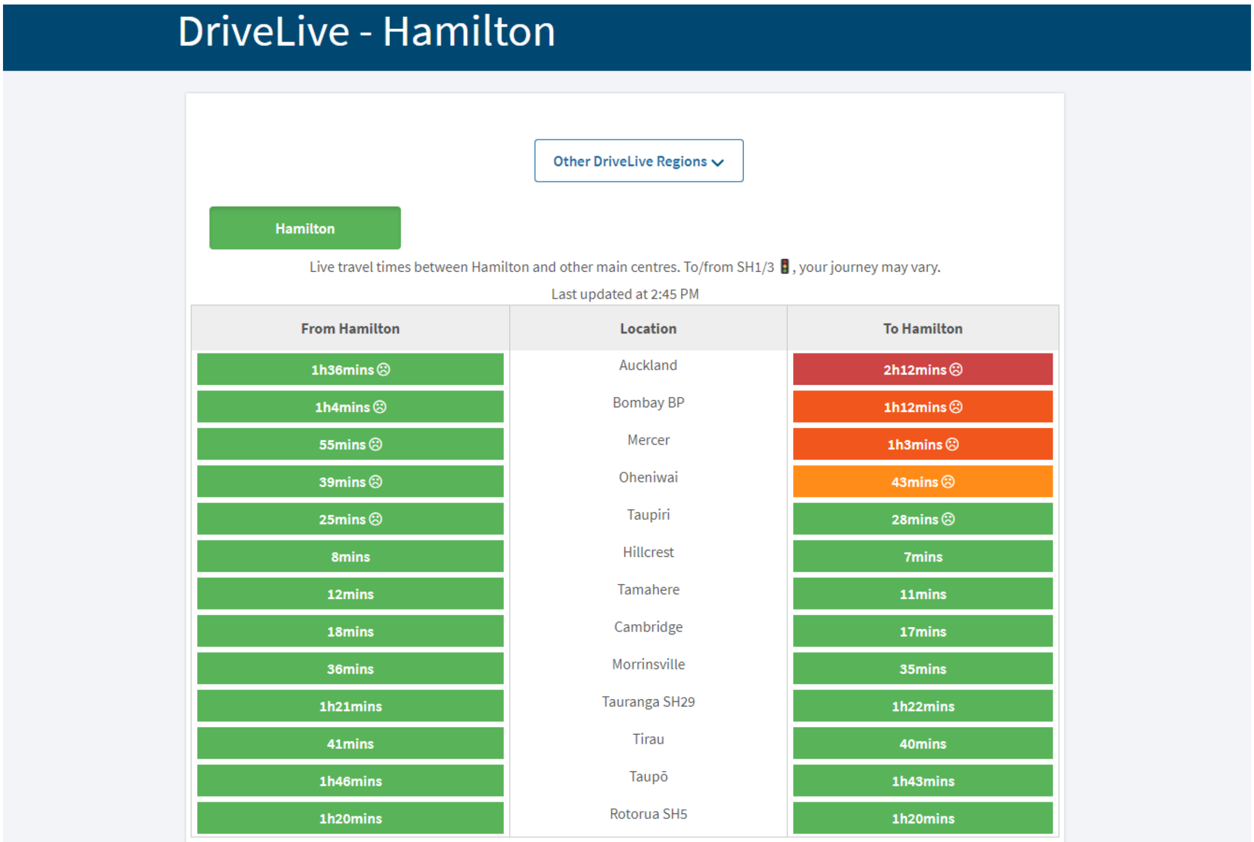
The stakeholders identified a range of real-time technologies being implemented across New Zealand, many of which have previously been described in the literature review (chapter 3). A summary of the technologies identified, their use and application in New Zealand are given in appendix A. Some key themes in terms of information needs and emerging applications are discussed below.

Real-time information needs and applications identified by maintenance contract managers and journey managers related to planned events, unplanned events, weather impacts and the delivery of traveller information. For planned events, stakeholders identified examples of how real-time technologies are used, or could be used, to monitor the network impact of TMPs, including:

- measuring traffic flows through temporary works
- scheduling of construction activities
- measuring contractors’ response times to incidents.

Journey managers currently use reporting dashboards which consider predictability (mainly associated with urban areas), throughput, safety, customer satisfaction and network availability. Real-time data can benefit network managers, journey managers and contractors through enabling improved response times to changing network conditions. DriveLive (www.drivelive.nz) is an example of a dashboard used by journey managers to monitor how the network is functioning. Drivelive relies on Bluetooth detection networks reporting on vehicle travel times, as well as reporting on whether conditions are improving or deteriorating over time (figure 4.1).

Figure 4.1 DriveLive dashboard showing travel times and conditions



DriveLive - Hamilton

Other DriveLive Regions

Hamilton

Live travel times between Hamilton and other main centres. To/from SH1/3, your journey may vary.

Last updated at 2:45 PM

From Hamilton	Location	To Hamilton
1h36mins	Auckland	2h12mins
1h4mins	Bombay BP	1h12mins
55mins	Mercer	1h3mins
39mins	Oheniwai	43mins
25mins	Taupiri	28mins
8mins	Hillcrest	7mins
12mins	Tamahere	11mins
18mins	Cambridge	17mins
36mins	Morrinsville	35mins
1h21mins	Tauranga SH29	1h22mins
41mins	Tirau	40mins
1h46mins	Taupō	1h43mins
1h20mins	Rotorua SH5	1h20mins

Real-time information is key in the delivery of traveller information. Delivering timely travel warnings and updates plays an important role for the TOCs in managing travel on the network and reinforces the road user focus underpinning network management. Platforms such as TREIS and National Incident and Event Management System (NIEMS – currently in development) support the management and dissemination of incident and event related information.

Stakeholders working in asset management identified that One Network Road Classification levels of service and NOC operational performance measures are also used to measure network and asset performance. Some of these measures include target response times which would be useful to monitor in real time.

Some stakeholders identified an opportunity to extend the use of GNSS technologies to identify and locate unplanned events on the road network. Unplanned event monitoring requires network-wide coverage and the use of analytics to identify when problems are occurring and to identify the location of the source (for example the location of a breakdown or crash) leading to a deterioration in network performance.

4.1.2 Timeliness of data

The timeliness of the receipt of data was a key theme discussed during consultation, noting that the importance of the receipt of timely data will be sensitive to the specific information needs. All stakeholders agreed that receiving timely and accurate information is critical to network management activities as this provides managers with the opportunity to respond quickly to changing network conditions.

Critical network management information (for example information regarding unplanned events) and network status information for travellers generally needs to be as real time as possible; however, views differed on how critical real-time information was for asset management, particularly for asset condition monitoring. While acknowledging the importance of accuracy and task repeatability, some stakeholders felt that the benefits of real-time technologies for asset management were limited as deterioration in the condition of assets is a relatively slow process. There are, however, opportunities for real-time data collection to assist in reducing response times to repair defects and to improve process efficiency.

4.2 Opportunities

Stakeholders were questioned about future opportunities that real-time data offers network and asset managers and road users. Their responses and suggestions are discussed below.

4.2.1 Innovation

Stakeholders considered New Zealand to be at the forefront of the development of ITS technologies and applications. The Ministry of Transport's action plan identifies the ongoing commitment of the government to promote New Zealand as a receptive test bed for new ITS technologies.

A general theme through the stakeholder consultation process was a push to make Transport Agency data freely available to other parties and in so doing encourage innovation and development of new applications and potential future opportunities.

It was considered by some that contractors and technology vendors are more receptive to innovation than government agencies. There was a view that contractors tend to be more driven and receptive to innovation and adopting new technologies. Technology vendors also demonstrated a willingness to engage with central government to explore how real-time data can be used to assist central and local government in managing assets and networks.

4.2.2 Analytics and data fusion

Many stakeholders identified opportunities to harness the power of real-time data through real-time analytics and data fusion. With many real-time datasets currently available to RCAs and contractors, further use, fusion and analysis of this information capitalises on current investments. For travel time analytics, this could include comparing real-time data with historic data to highlight network activity that sits outside the 'normal', rather than simply highlighting travel time delay or congestion across the network. Several stakeholders suggested that fusing data from multiple sources increases the reliability and accuracy of real-time data, for example by integrating Bluetooth and GPS data sources.

4.2.3 Real-time platforms

A platform-based 'plug-in' approach to integrating data sources was identified by the technology stakeholders as an opportunity to support data fusion, scalability and to avoid relying on specific detection technology inputs. Some technology providers are already building these platforms for adoption in New Zealand. An example of this is the 'Kite' sensor network and Cloud City Operation Centre being used as part of the Smart Cities imitative in Wellington city.

Efficient data storage and management of large real-time datasets and feeds supports scalability across the transport network. Commodity open-source software packages such as Apache Hadoop, which is designed for large-scale processing and storage of big datasets, are now commonly available.

4.2.4 Other observations

Other key observations and opportunities identified by stakeholders included:

- the potential use of data generated by future technologies such as connected and autonomous vehicles
- the ability to use real-time data in a different way, for example managing smart motorways based on volume thresholds being reached as opposed to being managed by time of day.

4.3 Challenges and constraints

4.3.1 Risks of reliance on real-time datasets

A key theme that emerged was questions around the ability to make sense of rich real-time datasets or 'big data'. It is especially important that this data is presented in such a way that it provides useful information for transport network operators and road users. One stakeholder summed up this challenge by the quote: 'getting the right information, to the right people, in the right language'.

The risk of mismanaging big real-time datasets extends to understanding the quality and limitations of that data. For example, the DriveLive website presents 'real-time' travel times based on Bluetooth detectors, which are sourced from vehicles that have completed the trip (that is they are 'end of trip' values), therefore the currency of the data is limited to the end period reported and conditions may have changed for road users about to embark on the same journey. This difference is exacerbated where Bluetooth detectors are widely spread on the network.

Incomplete or inaccurate data was noted by some stakeholders as a risk of relying on real-time data. One stakeholder acknowledged that by validating real-time data against other historical data sources, users can gain an excellent understanding of the quality of, and any limitations in, the application of the data for practical purposes. A single source of truth was deemed important, therefore measures to prevent third-party users from corrupting or misusing data need to be considered.

Other risks identified by stakeholders included:

- communication problems in remote areas that affect the reliability and/or geographic coverage of real-time data feeds
- concerns regarding the privacy of information (including the use of drones)
- commercial sensitivity of information conveyed through real-time data sets, for example the identity, composition and travel patterns of fleets contributing telematics data
- over-reliance on technology being a risk if the technology fails or is unreliable
- restrictive procurement processes that may stifle the ability to source and analyse real-time data sets to their full potential.
- significant amounts of data are already collected and not being used to their full potential, therefore the same might occur with real-time technologies and datasets.

4.3.2 Diverging approaches to real-time technology development

A key finding from the stakeholder consultation was the inconsistency in the application of technology across regions. Stakeholders highlighted that some applications of ITS and traffic management are not applicable to rural state highway locations.

There was a view that contractors tend to be more driven and receptive to innovation and adopting new technologies; however, due to competition between contractors, that can lead to different approaches being developed to tackle the same problem. This leads to the risk that different technologies and platforms developed by independent contractors do not align in a nationally consistent approach to real-time data collection and information sharing. Innovation driven by contractors can also be limited by investment constraints linked to contract length. This potentially indicates a lack of clear common purpose or strategy towards the application of real-time technology in network and asset management activities.

5 Classification of technologies and applications

The literature review and stakeholder engagement identified a range of sensor technologies, analytics platforms and applications for network and asset management. Initially the project team intended to undertake a matrix assessment of these technologies against network and asset management tasks to identify future opportunities; however, the range and complexity of technologies made this an impossible task. Instead the team decided to classify technology applications against 'activity areas' of network and asset management tasks. These activity areas were then used to guide the stakeholder workshop (chapter 6) in identifying broad opportunities for technology application.

The six asset and network management activity areas that could benefit from real-time technologies were introduced in section 2.6 of this report and are:

- detecting and responding to network incidents
- managing planned events
- monitoring weather impacts
- managing hazards
- asset and site surveying.
- structural asset monitoring and operations.

5.1 Detecting and responding to network incidents

Fast and accurate identification of incidents on urban networks ensures that network and journey managers can intervene and respond sooner and more effectively. Therefore, the real-time need for this activity area is the identification of the location and cause of unusual or unexpected network activity, such as lengthy delays or widespread congestion. The focus is predominantly on urban areas, where the impact of congestion on travel times may be considerable. Real-time technologies that are used or show potential in this area are outlined in table 5.1 alongside the analytical and display requirements to convert the sensor technology data into a meaningful and useable output.

Table 5.1 Real- time technologies for network incident detection

<table>
<tr><th>Information need</th><th>Sensors</th><th>Analytics</th><th>Outputs (display/response)</th></tr>
<tr><td>Vehicle speed
Travel time</td><td>GPS/GNSS
Bluetooth/Wifi
Fibre optics</td><td rowspan="3">Compare real-time conditions with historic (expected) conditions using algorithms to assess and quantify whether conditions are abnormal.</td><td rowspan="4">Road users: websites, map and dashboard displays and roadside signage eg VMS.
Network managers: SMS/email and other types of alerts, dashboards and monitors etc.</td></tr>
<tr><td>Queue lengths</td><td>GPS/GNSS
CCTV
Fibre optics</td></tr>
<tr><td>Number of vehicles</td><td>CCTV
Radar
SCATS
Tubes and loops</td></tr>
<tr><td>Cause/nature of event</td><td>GPS/GNSS
CCTV
Crowdsourcing</td><td>Identify and classify the type of incident.</td></tr>
</table>

5.2 Managing planned events

The real-time information needs focus on monitoring network conditions surrounding planned events that are subject to a TMP. The impacts due to planned events include unexpected delays and congestion as well as health and safety impacts regarding vehicle speeds through worksites. Real-time information can also help to dynamically adjust the TMP based on real-time conditions, for example extending hours of work (if allowed) when peak traffic volumes are lower than expected. Technologies that are used or have potential in this area are outlined in table 5.2.

Table 5.2 Real-time technologies for planned event management

Information need	Sensors	Analytics	Outputs (display/response)
Travel time	GPS/GNSS Bluetooth/Wifi	Compare real-time conditions with historic (expected) conditions using algorithms to assess whether conditions are abnormal or outside expected impacts.	Network managers and contractors: alerts when certain thresholds are met (eg SMS/email), dashboard reporting. Layout of TMP altered to reflect changing conditions. Identify opportunities to extend active TMP time if conditions allow. Road users: websites and dashboards (eg DriveLive).
Queue length	GPS/GNSS CCTV		
Intersection delay	SCATS		
Vehicle speed	GPS/GNSS Bluetooth/Wifi	Compare against acceptable safe speeds for event or worksite.	

5.3 Monitoring weather impacts

The real-time information needs in this activity area involve understanding the impacts of weather conditions on road users and the road network. This information can be used reactively, or where possible, proactively to forecast future conditions. Accurate reporting of road and weather conditions enables contractors to maintain roads more effectively, for example through better use of de-icing agents. There is also an overlap between this activity area and hazard detection (refer section 5.4). Technologies that are used or have potential in this area are outlined in table 5.3.

Table 5.3 Real-time technologies for monitoring and forecasting weather impacts

Information need	Sensors	Analytics	Outputs (display/response)
Rainfall	Mobile weather stations (vehicle mounted) Roadside weather stations Wider weather station network	General forecasting Road forecasting Thermal mapping	Winter road maintenance (de-icing/gritting) Road closures/opening Prepare operational resources in advance of weather event Road user information Dynamic signage Variable speed limits Operational resources including staff and plant planning.
Water film			
Humidity			
Chemicals (eg de-icing agent)			
Freezing point			
Wind			
Visibility			
Road temperature			
Ambient temperature			
Snow depth			

5.4 Managing hazards

A primary function of RCAs is the safe operation of their assets. This includes managing hazards to avoid and reduce potential risks to customers. To support this, road managers need to understand when a significant hazard is unfolding, or where a defect has the potential to become hazardous.

Technologies that support this activity area are outlined in table 5.4. Because weather conditions (eg avalanches and flooding) are responsible for many road hazards, there is overlap between this activity area and monitoring weather impacts (section 5.3).

The focus for this activity area is predominantly on rural roads where hazards are more prevalent and the quality and availability of communication networks may be a constraint in these locations.

Table 5.4 Real- time technologies for managing hazards

Information need	Sensors	Analytics	Outputs (display/response)
Slope/ground movement	MEMS Lidar/laser survey CCTV Fibre optics Radar	Motion detection (detect and quantify degree of change over time).	Send alert to network/asset managers that hazardous conditions are developing. Trigger roadside signage/lights in some situations (eg imminent flooding risk). Send contractor to respond.
Water level (flood risk)	River/lake level recording stations	Identify/model flooding risk (in combination with weather monitoring).	
Avalanche risk	Snow pit studies Specialised weather monitoring	Identify/model avalanche risk (in combination with weather monitoring).	
Other incidents (eg crashes, near-misses, wandering stock)	Crowdsourcing Source of truth (emergency services, contractors, police)	Confirmation that the report is correct.	Send contractor and/or emergency services to respond.
Surface roughness	Smartphone sensors (eg Roadroid)	Detect significant deterioration in road surface.	Send contractor to respond.

5.5 Asset and site surveying

This activity area involves using real-time technologies that reduce the time it takes to survey roads, roadside assets and other incidents or potential hazards alongside the road. Generally, the need for these surveys is less urgent than managing hazards and risks. For example, this might include surveying gradual slope movement or coastal erosion, rather than responding to an urgent rockfall or road drop-out that is a threat to human safety. Using real-time technologies for these applications minimises or eliminates the impact on road users through the application of surveying methods such as UAV, in-vehicle and vehicle mounted sensors. Technologies that support this activity area are outlined in table 5.5.

Table 5.5 Real- time technologies for asset and site surveying

Information need	Sensors	Analytics	Outputs (display/response)
Location and/or condition of assets	UAV and vehicle-based platforms: LIDAR/laser scanning Video inspection	Building information modelling (BIM) 3D modelling	Send alert to asset managers and contractors.
Understanding sites that are difficult to access (eg cliff faces)	UAV platforms: LIDAR/laser Video inspection	3D modelling	
Crash scene investigation	Fixed site and UAV platforms: LIDAR/laser scanning	3D modelling	
Pavement condition	Radar/ground penetrating radar		

5.6 Structural asset monitoring

Large structural assets such as bridges and tunnels require on-going monitoring to ensure they are operating safely and are not being subjected to conditions that threaten their integrity. Incidents or environmental conditions that impact on these structures may be gradual, for example wear due to age or continuous vibration, or sudden, such as an overweight vehicle on a bridge. It is important for asset and network managers to know when a structure has been compromised or if critical systems experience faults so maintenance or other follow-up actions (eg enforcement) can be undertaken. Technologies that support this activity area are outlined in table 5.6.

Table 5.6 Real- time technologies for structural asset monitoring

Information need	Sensors	Analytics	Outputs (display/response)
Structural deformation Vibration	Optical fibre sensors	Structural health monitoring	Asset managers: Send an alert that an asset may need inspection or maintenance. Network managers: Send alerts regarding hazardous conditions requiring network management, eg closure of asset, deploy road inspection team. Road users: Send roadside alerts for over-height vehicles, automatic road closures. Enforcement of over-weight and non-compliant vehicles.
Asset fault detection (eg for signals, ventilation, lighting and hazard detection systems)	Various electrical/mechanical sensors	Identification of fault, including fault location and fault type.	
Fire/smoke	Smoke and fire sensors	Automatic incident detection	

Information need	Sensors	Analytics	Outputs (display/response)
Unexpected activity (eg pedestrians, wrong way vehicles)	CCTV	(includes video analytics where CCTV is used).	
Vehicle height	Laser CCTV	Identify vehicles exceeding height limits.	
Vehicle weight and number of axles	Weigh-in-motion	Identify vehicles exceeding weight limits.	
Vehicle identification	CCTV	ANPR for vehicle identification – used in conjunction with vehicle weight to check compliance.	

6 Stakeholder workshop

A workshop with the steering group was held in May 2017. The workshop presented the early findings from the literature review and stakeholder consultation, and sought to identify opportunities based on the activity areas identified in chapter 5.

The workshop included participants from the Transport Agency (network managers, journey managers and asset integrators) and the Christchurch City Council. The workshop involved the following steps:

1 Establish context and present findings to date

2 Outline the activity areas and associated real-time technology needs

3 Conduct an initial ranking exercise of activity areas

4 Facilitate an interactive case study scenario exercise

5 Conduct a second ranking exercise based on findings from the interactive exercise.

6.1 Interactive case study scenarios

Interactive case studies were developed by the research team to cover a range of real-time data and technology opportunities and network and asset activity areas. The purpose of this exercise was to determine a baseline of current data needs and identify opportunities or constraints imposed by the application of real-time technologies.

The case study scenarios covered the following three events:

- rural weather event coupled with a natural hazard incident
- urban unplanned event where traffic management is in operation
- an asset lifecycle study.

Each scenario took place in 'time steps' (that is before, during and after) as an event on the network unfolded. The participants looked at which activities were occurring before the event, during the event (when details of the event were disclosed) and following the event. During this facilitated exercise participants described the process of activities and technologies that would inform their individual roles as part of each event.

The objective of these case studies was to provide additional insight into the roles of the participants, the extent to which they currently use real-time technologies and the constraints and additional considerations in responding to each scenario. The study team summarised the findings of this exercise in the sub-sections that follow.

6.1.1 Rural weather-related scenario

The rural scenario consisted of a landslip event causing closure of a key rural road during heavy snow.

Table 6.1 Rural weather scenario outcomes

Timeframe	Activity	Data/technologies used	Comment
Before	Prediction of road conditions Resource planning (availability of contractors, de-icing agents etc) Thermal mapping (predicting temperatures at different locations)	Weather forecasting (MetService) Contractor communications	Weather forecasts are generally not precise enough to aid decision making. Weather data provided on a 24-hour time scale but need to know when the road freezes.
Before	Notify public of forecast	TREIS Websites Social media and radio	
During	Receive notification of incident (contractor or road user calls it in) Verification of location and size Deploy clean-up resources	Mobile phone/landline to phone in observations from the site. Radio (Fleetlink) and phone for contractors.	Communications coverage is limited in remote areas, so there can be a delay in both responding to an incident and advising customers promptly. Very little opportunity for widespread automatic monitoring of slips as this is an issue across many rural roads where slips can happen almost anywhere. Opportunity to improve communications so customers can be alerted sooner. Satellite communications are rarely used. It was noted that information may come in during the event through other agencies (eg councils, Civil Defence, NZ Police, Fire Service).
During	Set up detours (if necessary)	Use local knowledge.	
During	Keep customers informed	TREIS Websites Social media and radio VMS (where installed) Text alerts (On the Move)	
After	Track response times Measure contractor performance	Vehicles are tracked for billing purposes and contractor performance (ERoad). Photographic evidence and reports from people on-site.	Real-time vehicle tracking is not useful for network/asset managers as the event is unfolding, but it can be used to measure contractor performance against expected levels of service.

6.1.2 Network incident (urban network)

The urban unplanned event scenario involved a busy section of motorway under construction with a TMP. Under the TMP the contractor should remove the traffic management in advance of the morning peak; however, the works extended and a lane closure remained in place. At the same time, a vehicle breakdown occurred about 1 km south of the planned works.

Table 6.2 Network incident scenario outcomes

Timeframe	Activity	Data/technologies used	Comment
Before	Understanding the TMP, including when traffic management will be removed.	Phone communications (updates) between the site traffic management supervisor, the TOC and journey manager.	This would not usually be an issue if it was a rural area. Communications regarding the TMP are led by the contractors, not the TOCs. TOCs should not lead this as they do not have a full view of conditions on site.
During	Understand the impact of the delayed TMP to understand impacts on the network.	Existing traffic monitoring, including Bluetooth Local knowledge (in terms of understanding network impacts)	Lots of data collected but not used to their full potential. Analytic systems could be improved. Would be good to understand origin-destination data and comparison of real-time against historic travel times to predict which parts of the network would be most affected by the lane closure and breakdown. It is very difficult to make predictions as every day and every situation is different. Traffic monitoring systems need human interpretation to understand what is happening and which roads will be affected.
During	Verification of incident (breakdown)	Location of breakdown and how it is affecting traffic. Visual confirmation or CCTV	Crowdsourcing has potential here but is an emerging area that is not fully implemented.
During	Keep road users informed	Social media VMS Bluetooth Drive Live	Recognition that human intervention has a role to play in sending out messages to the public.
After	Not required		

6.1.3 Asset lifecycle study

This case study involves an asset life cycle study with a critical incident affecting bridges and tunnels. Two scenarios were proposed and tested, one whereby an earthquake affects a structure, and the other where an over-dimension or overweight vehicle travels over/through the structure.

Table 6.3 Asset lifecycle scenario outcomes

Timeframe	Activity	Data/technologies used	Comment
Before	Maintain structures in safe working order. Monitor for critical incidents such as over-dimension vehicles or wrong-way drivers.	Asset monitoring undertaken based on the life and criticality of asset. Old Mangere Bridge in Auckland is the only bridge that is monitored in real time (reporting every two minutes). Tunnels also monitored in	Level of monitoring (including real-time monitoring) depends on the criticality of the structure. Real-time monitoring would enable improved response and assessment times when an incident occurs. Most tunnel monitoring technology requires human intervention (assessment) before a response is actioned.

Timeframe	Activity	Data/technologies used	Comment
		real time using automatic video incident detection (except for Homer Tunnel). River flows are monitored to understand impacts on bridges. Auckland Harbour Bridge is monitored (but not in real time) to understand its useful life. Real-time technologies include monitoring: • light levels • pedestrian detection • wrong way detection • smoke detection • air quality • WiM • strain gauges CCTV and video analytics	Health and safety benefits associated with the use of technology over visual inspections (eg in terms of not putting people in dangerous places); however, technologies do not always pick up what the eye can see (through a visual inspection). Sending someone for an on-site inspection is usually cheaper than real-time monitoring.
During	Identify risk of damage to structure following earthquake	Visual inspection dependant on magnitude of event. Helicopters may be used for access if a large-scale event occurs.	Real-time monitoring would enable improved response and assessment times. Seismic impacts on assets not currently monitored. Communication networks often damaged by earthquakes.
During	Detect that the incident has occurred or is about to occur. Alert/ inform/ divert overweight/ height vehicles	Over-height detection systems WiM	Accuracy of WiM data prevents it from being used for enforcement.
After	Update maintenance and renewal programmes	Inspections (visual)	Data captured during the incident can be used to understand the remaining life of a structure. While not useful in real-time this helps with setting asset maintenance and renewal programmes.

6.2 Activity area ranking exercise

To form an initial baseline, the workshop participants were asked to form a consensus view on whether the different activity areas provide high, medium or low potential in terms of the opportunity to benefit from the application of real-time technologies. For example, activity areas ranked as 'low' signified there is already substantial real-time technology in use, or where real-time technologies had little to offer in terms of additional benefits.

The workshop concluded with a final ranking exercise based on the outcomes from the workshop discussions. The ranking was informed by the criticality of the opportunity, therefore areas with the strongest relationship to safety and risk minimisation receive the highest rankings as shown in table 6.3.

Table 6.4 Outcome of ranking exercise

Activity family	Ranking	Comments
Network incidents	High	This activity area is highly variable in terms of the current application of real-time technologies. Differences between application in urban and rural areas were noted. For example, a 30-minute delay in receiving data from a rural environment is sufficiently 'real-time' and therefore acceptable, whereas urban areas should generate and communicate real-time information more quickly.
Managing planned events	Low	Participants agreed this was an area which is already being managed well; however, there is scope to maximise the value of technologies currently being used to assist with identifying network incidents. This is preferable to investing in new platforms. Consistency between regions is an issue.
Monitoring weather impacts	Low	Areas impacted by adverse weather and how to manage this, are generally well understood. Existing data is not always available or useful and emphasis should be placed on improving the use of existing real-time data/technologies. It was agreed that Metservice is successfully using real-time technology to meet information needs in this activity area.
Managing hazards	High	Participants rated this activity area as showing 'high' potential due to the safety focus and risk-based approach to managing roads, especially in rural environments. This area is driven by contractor response times as outlined in NOC contracts.
Asset and site surveying	High	This activity area was rated as showing high potential to benefit from real-time technology, as the data needs are generally required within a short timeframe.
Structural asset monitoring	High (for critical assets only)	Participants agreed that the benefits of real-time monitoring only apply to assets which are considered 'critical' to protect them from failure.

6.3 Opportunity identification

Throughout the discussion and the case study scenarios several key themes emerged regarding opportunities to improve upon or expand the use of real-time technologies. These opportunities have been summarised in table 6.5. Activity areas with the most to gain from these opportunities are listed alongside each opportunity.

Table 6.5 Opportunities by activity area

Opportunity	Activity area					
	Network incidents	Planned event management	Monitoring weather impacts	Hazard and risk management	Asset and site surveying	Structural asset monitoring and operation
Improved communications – explore opportunities for improving mobile network coverage and communication options in remote areas. This is the biggest barrier to the use of real-time technologies in rural areas.	Y			Y		Y
Improved identification of incidents – improved identification and verification of unexpected incidents on the road network ensures a faster response and keeps customers informed. Defects and hazards are resolved as per contractual requirements and reduce risk to road users.	Y			Y		

Opportunity	Activity area					
	Network incidents	Planned event management	Monitoring weather impacts	Hazard and risk management	Asset and site surveying	Structural asset monitoring and operation
Improved use and integration of existing data – use existing data more effectively by making it more widely available or by undertaking advanced analytics.	Y		Y	Y		
Improving the accuracy of existing systems – improve the accuracy of existing real-time systems to reduce the need for manual intervention and to support enforcement.	Y		Y			Y
Safer inspections – use real-time technologies to monitor assets to reduce the health and safety risk for inspectors by removing the need for frequent on-site inspections.					Y	Y
Support more effective asset management – continuous real-time monitoring of assets supports more effective planning of maintenance and replacement programmes.				Y	Y	Y

7 Feasibility case studies

This chapter presents two case studies which assess the feasibility of real-time technologies to support the network and asset management activity areas identified in previous stages of the research. The case studies are assessed to identify the advantages, disadvantages and transferability of these applications to other areas of network and asset management. The case studies assess feasibility in the context of the following questions:

1 Does the real-time technology adequately support the intended information need?

2 Is the real-time technology readily available and is the data output accessible?

3 Is the value added by the real-time component offset by any additional investment required?

4 Are there particular circumstances where users should or should not use real-time technologies?

5 What risks or weaknesses are associated with the real-time technology?

The two case studies selected for feasibility assessments were:

1 Real-time monitoring of slope stability, rockfall and seismic activity along the Kaikoura Coast by the North Canterbury Transport Infrastructure Recovery alliance (NCTIR)

2 Using real-time Google GPS travel time data for monitoring planned and unplanned events.

7.1 North Canterbury Transport Infrastructure Recovery

NCTIR was formed by the New Zealand Government in December 2016 to repair the road and rail infrastructure along the Kaikoura Coast following a magnitude 7.8 earthquake in November 2016. The alliance includes the Transport Agency, KiwiRail, HEB Construction, Fulton Hogan, Higgins and Downer. As part of the reconstruction, NCTIR looked for ways to improve the resilience and safety of the network, both during and after construction.

Figure 7.1 Damage to the road and rail network following the Kaikoura earthquake (Source: NZ Transport Agency

Kaikoura's coastal network was severely affected by the earthquakes, with much of the road (State Highway 1) and rail network destroyed by landslides and ground movement (figure 7.1). With limited access and highly unstable slopes, it is a challenging environment for the contractors to work in.

NCTIR has invested in several remote monitoring systems along the rail and road corridor. These systems gather data on site conditions and transmit this in real-time to inform or predict incidents occurring on or around the road and construction sites. While NCTIR's focus in real-time technologies is primarily to ensure the safety of workers and protect assets, there are several lessons emerging from applying real-time technologies in remote areas that could be applied in network and asset management applications elsewhere.

These monitoring systems include:

- real-time monitoring of factors that could lead to a slip, including slope movement, seismic activity and the build-up of pore water pressures
- periodic monitoring of landforms and structures to record long-term movement, including survey techniques such as prisms and 3D scanning, strain gauges, extensometers and tape measurements.

The outputs of these monitoring systems include (NCTIR 2017):

- immediate notification of rockfall or debris fall that compromise the rail track and rail operations
- alerts when meteorological, coastal and river level measurements and forecasts suggest conditions will affect construction and rail operations
- predictive lost-time expectations based on historical data, to assist in construction programming
- alerts when seismic activity, pore water pressures or when physical movement is detected at a level that will impact on the safety of construction activity and rail operations.

7.1.1 Rockfall and slope stability monitoring

NCTIR operates rockfall monitoring systems at approximately 35 sites along the rail corridor. Each site costs about $20,000 and consists of a lightweight slip barrier fence (rockfall protection fence) with a spring/linear potentiometer (trip wire). The string potentiometer is activated if there is significant movement of the fence and can detect movement as small as 1–2 mm.

These sites are also monitored using a static camera with a pan-tilt-zoom function (long range and high definition). Static cameras take photos periodically (typically every 30 minutes) along the wire with additional images taken if an activation occurs. CCTV is also deployed with the ability to zoom in and check the activation before deploying personnel to the site.

Solar-powered dataloggers are connected to the tripwires mounted on the rockfall arrest fence. A mobile network connection is used to transmit alerts and photographs to a control centre (figure 7.2).

Figure 7.2 Tripwire system mounted to rockfall arrest fence (Source: NCTIR)

NCTIR also uses Senceive tilt sensors to detect land/slope movement. The Senceive system consists of FlatMesh dual axis tilt sensor nodes positioned across the slope surface. These are connected to a central Gateway unit, providing real-time 3D monitoring of slope movement. When pre-set trigger levels are met, alerts are automatically generated (NCTIR 2017). Site conditions can also be monitored online (figure 7.3).

Figure 7.3 Slope monitoring website

Intelligent fibre-optic based technologies have been identified as a potential long-term monitoring solution to supplement or replace movement detection systems currently in use along the Kaikoura Coast (NCTIR 2017) and have applications elsewhere on the rural state highway and local road networks.

7.1.2 Seismic advanced warning systems

Immediate notification of an earthquake is critical in terms of keeping construction teams safe and ensuring the safe operation of road and rail links. Even a few seconds warning gives construction crews time to move away from high-risk locations.

Early detection of an earthquake can be achieved by monitoring for P waves (primary waves). These waves promulgate faster than S waves (secondary or shear waves) and therefore the measurement of P waves gives a more rapid alert to seismic activity. P waves can be detected by using Sanlien 'pAlert' monitors (figure 7.4). which use MEMS to detect motion.

Figure 7.4 pAlert monitor by Sanlien (Source: NCTIR)

The system calculates the size of a seismic shock wave within seconds, providing 20 to 30 seconds warning, depending on the location. This enables people working in the area to move, or for the location of trains in the area to be identified. Alerts can be set up to activate at predetermined trigger levels based on risk and mitigation analysis, as well as known site conditions. These alerts are transmitted to mobile devices, as well as audible/visual alerts in machine cabs (NCTIR 2017).

The pAlert units are usually installed at sites with a fixed power supply and backup power supply, however they are also powered by battery and solar power in some locations. The units require a connection to the internet or local area network which can be achieved through mobile or satellite communication networks.

In summary, the pAlert provides advanced warning of earthquake activity that is faster than other warning and detection systems (eg GNS monitoring sites). However, the need for a reliable and robust power supply and communications network limits where these devices can be used.

7.1.3 Summary of opportunities and challenges

Table 7.1 summarises the opportunities and constraints of real-time technologies in use by NCTIR along the Kaikoura Coast.

Table 7.1 Summary of opportunities and constraints from the NCTIR Kaikoura case study

Application	Sensors	Opportunities	Constraints
Rockfall monitoring systems	Barrier fences, trip wires and camera/CCTV	Able to monitor difficult-to-access sites remotely. Early detection of rock fall or slope instability. Reduce the need for site visits or surveys. Advanced predictions and warnings keep construction workers safe.	Requires reliable mobile coverage. The range of the Senceive tilt monitors is limited so several systems would be required to monitor large areas.
Slope movement detection	Senceive tilt sensors		
Seismic activity monitoring	pAlert monitor by Sanlien	Provides advanced earthquake warning. Ensures workers can vacate high-risk sites.	Requires highly reliable mobile or other network communication coverage. Requires reliable power source (including back-up source).

NCTIR primarily uses real-time monitoring systems to protect the integrity of the rail network along the Kaikoura coast. There is an opportunity to extend these applications to the road network as well as other locations in New Zealand susceptible to land movement; however, these will be most suitable where there is:

- adequate communications coverage, for example mobile coverage.
- a significant risk to critical assets or human safety, for example on construction sites or in high-risk locations.

In addition to individual reports and triggers from each technology application, there is an opportunity to take an integrated approach to analysing the combined input of all data sources to predict and inform network and asset management decision making.

7.2 Real-time GPS for monitoring planned and unplanned events

This case study examines the use of real-time GPS data to:

- monitor planned events (TMPs)
- detect unplanned events across a large road network.

This case study was developed from the research and testing undertaken by Qrious using Google GPS data. The content for this case study is the result of interviews with Qrious staff as part of the stakeholder consultation and a subsequent follow-up meeting.

Qrious chose to work with real-time Google travel time data because of its wide coverage, market-leading accuracy and scalability across regions (Ward 2017). Google filters and prepares travel time data and makes this available through an application programming interface (API). Web applications can then be developed to extract, process and display travel time indicators for a range of purposes. Two examples of these are examined in this case study.

7.2.1 TMP (planned event) monitoring

Working with Fulton Hogan, Qrious investigated how Google travel time data could be used to minimise disruptions during a construction project under a TMP, by analysing delay times and queue lengths surrounding the roadworks site. A dashboard application was developed (figure 7.5) and alerts could be sent when queue lengths or travel times reached a defined threshold. These alerts included SMS messages sent to traffic management staff notifying them of delays and queue lengths along various approaches to the site. During an initial trial, the Google data was tested against CCTV camera data and on-the-ground observations to confirm its validity (Ward 2017).

The primary benefit of using real-time information from Google was minimising the disruption to drivers during the duration of the construction project. This was achieved by:

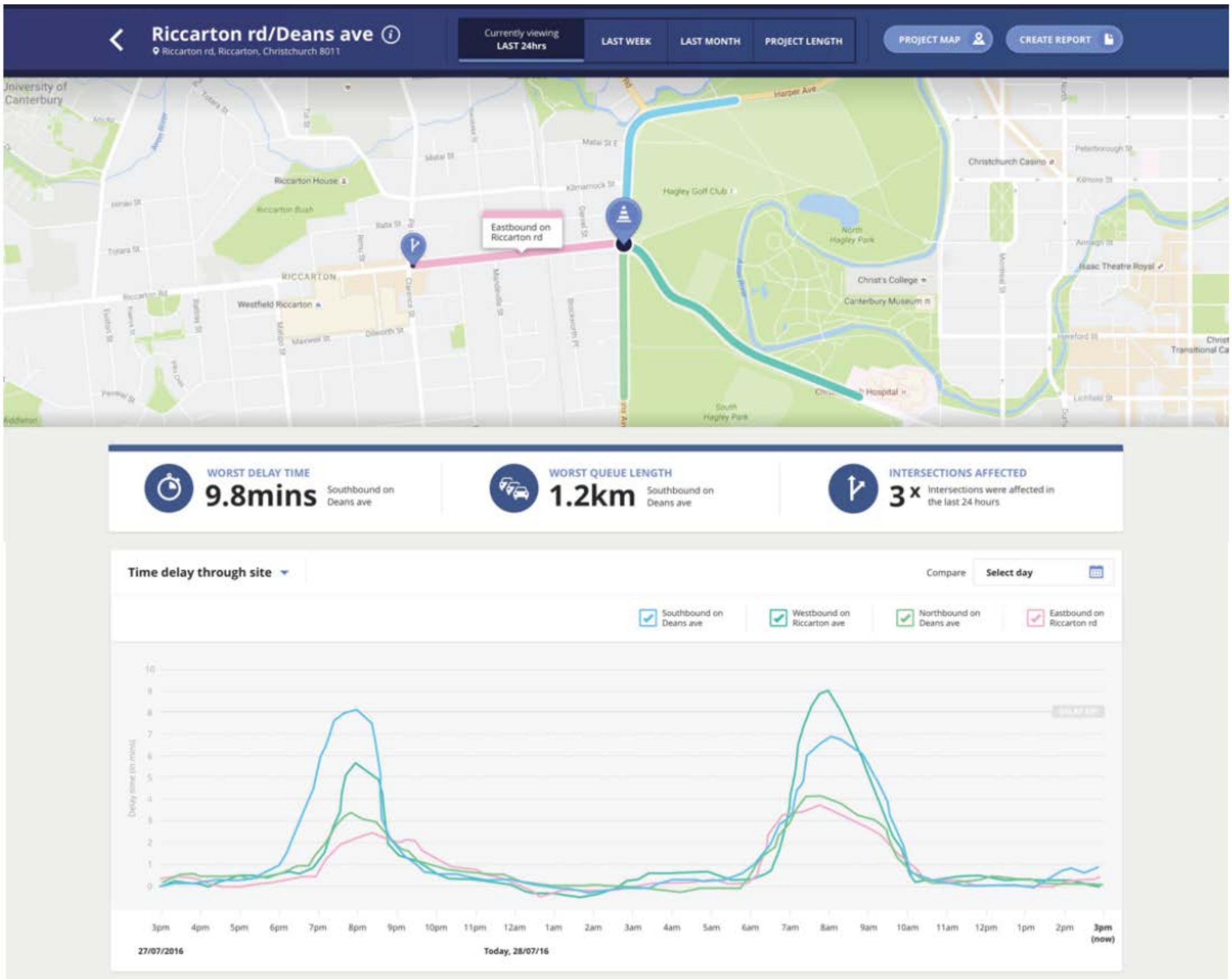
- monitoring congestion (queue length and travel times) on roads directly affected by the construction work
- monitoring congestion on the surrounding road networks to determine if this was likely to affect traffic flow through the site
- generating alerts when congestion levels exceeded a pre-determined threshold.

Traffic management controllers (on-site) could then use the alerts to intervene to reduce driver delay, for example by adjusting site layouts.

This type of analysis and mapping system has a number of other potential real-time applications, including the ability to:

- share this data with TOCs and clients
- test different traffic management strategies and observe how this affects travel time in real-time
- monitor vehicle speeds to ensure safe working conditions for road workers
- measure the performance of the TMP against key performance indicators for delay and travel time, including identifying factors outside the worksite that might explain unexpected delays.

Figure 7.3 Traffic management dashboard – travel time delay graph (Source: Ward 2017)



7.2.2 Incident detection

Another application of Google real-time GPS data explored by Qrious was improving incident response using a process called 'dynamic polling' (figure 7.6). 'Polling' refers to the process of sending a request for travel time data to the Google travel time API. Because of limits on how much data can be polled at one time, dynamic polling involves continuously retrieving data for a few longer sections of road across a network. If a delay is detected in any of these longer sections, further polling of shorter segments within that section is undertaken to zero in on the location of the delay. Using this process, Qrious could identify unusual network activity down to a 50 m segment and this logic could be applied to both directions of traffic (Ward 2017).

The Qrious dynamic polling algorithm was further refined to identify instances of abnormal congestion, as opposed to normal congestion associated with the time of day, or time of year. Parameters used to refine this algorithm included:

- severity of delay (as a percentage above normal)
- length of queued traffic
- a static ‘starting point’ for the location of the abnormal congestion
- congested segments ahead of the ‘starting point’
- location-specific delay trends (that is if this is a recurring issue)
- congestion on surrounding roads
- length of time ‘abnormal congestion’ is occurring (Ward 2017).

Figure 7.4 Visual representation of dynamic polling logic (source: Ward 2017)

The number of parameters used to refine the dynamic polling algorithm gives an insight into the complexity of interpreting the GPS travel time data. For each parameter, a threshold must be set and refined so the sensitivity of the output is neither:

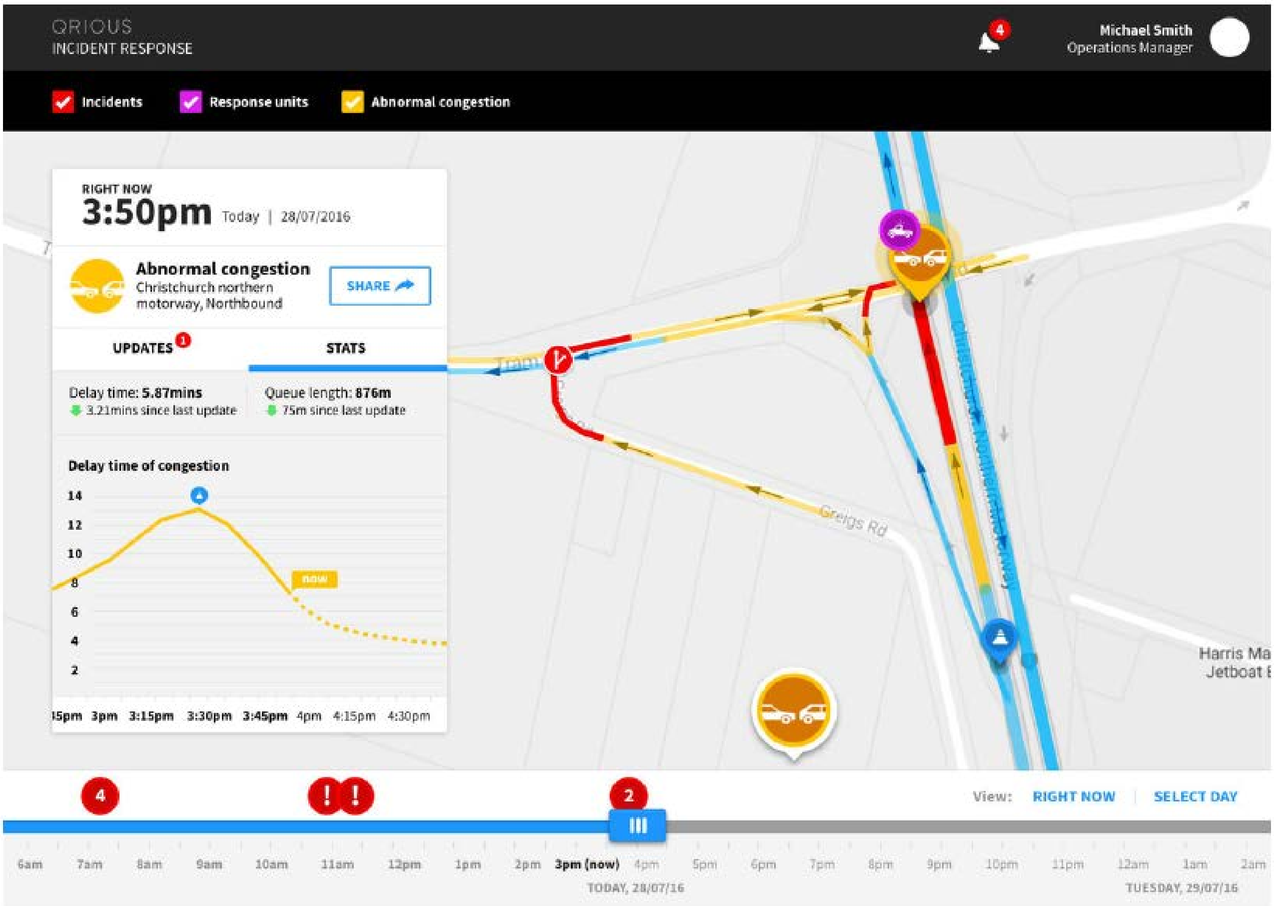
- too low – in which case users would be bombarded with alerts and messages, or
- too high – in which case some incidents remain undetected (Ward 2017).

To visualise the outputs a software application was also developed by Qrious (figure 7.7). The purpose of this application is to support incident response staff and TOCs in managing their response to an incident after it has been identified (Ward 2017).

The outcome of this project was an incident alert system that continuously monitors travel times over a large network. Enhancements to this system are ongoing to improve the reliability of incident reports, including validation against CCTV and TREIS data (Ward 2017). Using the concepts of dynamic polling and incident detection, many other applications are feasible, including:

- understanding the impact of an incident on traffic
- determining how many staff are required to manage traffic
- response coordination
- identifying the best detour route and understanding how it is performing.

Figure 7.5 Incident response prototype – monitoring detour performance (Ward 2017)



7.2.3 Summary of opportunities and challenges

Table 7.2 summarises the opportunities demonstrated by Qrious' experience using real-time travel time data to monitor planned and unplanned incidents and events.

Table 7.2 Summary of opportunities for using Google GPS data to monitor planned and unplanned events

Application	Opportunities
TMP (planned event) monitoring	Monitoring travel time and delay on roads affected by the TMP. Sending alerts to traffic management and TOCs when thresholds are exceeded. Providing regular reports on the impact of the TMP on traffic flow. Enabling traffic management controllers to dynamically adjust site layouts/operations in response to variable traffic flow. Enabling traffic management controllers to test different traffic management strategies and observe the impacts of this. Providing a means for contractors and clients to measure performance against key performance indicators for delay and travel time. Monitoring vehicle speeds through worksites.
Incident detection (using dynamic polling)	Identify incidents by detecting abnormal congestion. Understand the impact an incident is having on the network. Support incident response and coordination. Identify detour routes and monitor detour performance.

Despite the potential benefits, a number of challenges associated with using Google data for planned and unplanned event monitoring are identified, including:

- The data is complex and it is difficult to quantify ‘abnormal congestion’. More work is still required to refine these algorithms to prevent over- or under-reporting of incidents. If alerts generated by the system are not trusted by users they could be ignored. Further testing and validation is required to establish certainty in this system.
- Different approaches to monitoring planned/unplanned events are being developed by different contractors and TOCs, for example using Bluetooth over GPS data technologies and using different platforms for displaying data outputs.
- Caution should be exercised in relying solely on these technologies as a source of truth for identifying incidents. Other sensing methods (eg CCTV or confirmation with traffic management controllers) should be used to confirm what the data is indicating.
- Government agencies tend to want to ‘own’ a dataset, which is not possible using Google data (Ward 2017). In this case study Google retains ownership of the data, and TOCs and contractors are only able to query and display this using the API. It is possible to collect data from Google but only once polling has been established and there are limits on how much data can be retrieved at any time.
- The ‘black box’ nature of Google data means there is no complete certainty on how data is aggregated and the algorithms that are applied before it is released through their APIs. Validation of this data against known data sources is required to establish confidence in what is being reported.

8 Discussion

This chapter collates and summarises the key learnings across all stages of the research. These are structured to directly address the objectives of this research, which were:

- Identify both readily available and emerging technologies that can deliver real-time or near real-time data for network management and asset management purposes.
- Determine typical asset management and network management activities undertaken in New Zealand and recognise the information needs surrounding these activities.
- Identify the opportunities and challenges of providing real-time information to internal and external stakeholders.
- Assess the risks associated with an overreliance on real-time information, particularly for information sources with limited availability or of variable quality.
- Identify a best practice approach to the adoption or adaptation of technologies that provide real-time data.

The literature review identified a wide range of real-time technologies that can deliver for a range of transport applications. Throughout the course of this research many new applications were discovered and added to this chapter. The literature review therefore represents a snapshot of technologies currently in use today. A key learning from this research is that with the rate at which new technologies are emerging, it is challenging to keep abreast of real-time technologies currently in use across New Zealand, let alone internationally.

The range of applications combining different sensor types, analytical platforms and use cases made it impossible to develop a complete stocktake of real-time applications in use across New Zealand; however, opportunities and areas for further investigation opportunities are discussed in section 8.2 below.

The discussion of opportunities (section 8.2) and challenges (section 8.3) together set out best practice when developing real-time applications.

8.1 Real-time asset and network management needs

This research identified a wide and complex range of real-time information needs for asset and network management. At a strategic level, these needs are:

- keeping road users (including people working on the road) safe by responding to hazards and defects as quickly as possible
- delivering value for money (in asset management) by having sufficient data to understand and plan around the performance and condition of assets
- keeping networks moving by ensuring disruptions are minimised and keeping customers informed.

In chapter 5, the various information needs of stakeholders were aligned with the real-time technologies and technology platforms currently in use (or emerging). To provide some structure to the research going forward, these activities and information needs were grouped into seven activity areas (table 8.1).

Table 8.1 Real- time technology applications in network and asset management

Activity area	Real- time technology applications
Network incidents (predominately urban)	Understanding network conditions in order to identify the location and cause of unusual or unexpected events. Improving the speed and accuracy of incident identification and response enables network and journey managers to keep the network moving.
Planned event management	Monitoring traffic conditions around planned events such as TMPs in order to minimise the impact on road users and support safety around worksites.
Monitoring weather impacts	Understanding the potential impact of current and future weather conditions on road users and the road environment. This activity also supports winter road maintenance.
Hazard and risk management	Managing hazards to avoid or reduce potential risks to customers. This is achieved by understanding where significant hazards are developing, or where a defect has the potential to become hazardous.
Asset and site surveying	Using real-time technologies to reduce the time it takes to survey roads, assets and the roadside environment. Supports health and safety outcomes by removing or reducing the need for physical inspections (particularly for hazardous sites such as bridges and steep slopes)
Structural asset monitoring and operations	Monitoring the condition and operation of large structural assets such as bridges and tunnels to understand change over time and to identify when a structure has been compromised, for example by overweight or over-dimension vehicles.

It was found that not all activities have the same level of need for ‘real-time’ information. In asset management, real-time information (in terms of receiving an automatic or continuous stream of data) is only currently demanded for monitoring critical assets such as tunnels and certain bridges. However, further benefits arising from more and/or improved use of sensor technologies include:

- Improving the speed and safety of undertaking asset inspections, which in turn minimises impacts on road users. An example of this is using LIDAR scanning technologies attached to vehicles or UAVs.
- More frequent (ie continuous) collection of asset condition data which provides asset managers with a richer dataset to use when making decisions and planning asset maintenance. Such data can also be used to examine how the condition of assets changes over time, particularly in response to specific interventions or when subjected to adverse environmental conditions. An example of this is the Roadroid application which provides a rich and relatively real-time dataset on pavement condition that has been used for a range of purposes, including investigating the impact of different pavement treatments over time.

The demand for real-time information for network management was much higher than for asset management needs. Many of these demands are already met through existing real-time and non-real-time technologies; however, a range of opportunities to make better use of these, or to adopt new technologies was identified throughout this research.

8.2 Real-time opportunities

Many opportunities and challenges for using real-time technologies were identified in the literature review, stakeholder engagement, stakeholder workshop and feasibility case studies.

8.2.1 Faster incident identification

There is an opportunity to improve the rate at which incidents are identified and verified on the road network. Many real-time technologies are already used in this area, including GPS Bluetooth and CCTV detection systems and many stakeholders were generally comfortable with the level of detail provided by these systems; however, some opportunities to improve real-time detection were identified, including:

- crowdsourcing
- continuing to explore the use of GPS data and other emerging sources
- advanced analytics and algorithms that use both historic and real-time data to detect 'unexpected' congestion and delay.

Similar opportunities existing in rural areas; however, the speed at which incidents can be identified and reported is primarily limited by the constraints of the communication network.

8.2.2 Predictive real-time transport modelling

Part of incident response is understanding the impact of the incident on the wider network. This is particularly challenging as the scale of the impact varies significantly depending on the location, time of day, day of week, as well as other influences such as weather conditions and seasonal traffic demands.

Assessing the impact of an incident on the network is currently undertaken based on personal experience and local knowledge; however, real-time datasets combined with highly detailed historic datasets could feasibly be assessed to predict the scale and impact of the event, for example by identifying pinpoints and flow-on effects, both by location and over time. This could then be used to make interventions at other points in the network to minimise the impact, including setting detours and adjusting signal phasing, or to communicate the length of time before normal network operation will resume.

Variability across road networks and the ability to process vast amounts of data in real-time present the greatest challenge to this type of application.

8.2.3 Improved detection of defects

A critical function for network and asset managers is to be aware of hazards on or alongside roads, particularly in rural areas. Ensuring defects are identified and resolved early reduces safety risk and helps contractors meet targets under network operating contracts. The following applications have been identified as opportunities to improve the detection of defects:

- crowdsourcing applications
- improved rural communications
- vehicle-based road condition assessment, for example RoadRoid.

8.2.4 Keeping people safe in high-risk locations

Stakeholders involved in the research emphasised the importance of using real-time technologies to protect human safety, through the early identification of potential hazards and avoiding putting people (particularly road workers and contractors) in dangerous locations. This was exemplified through the Kaikoura case study where real-time technologies were deployed to provide advanced warning of earthquakes and slope instability. Specific applications that present an opportunity to keep people safe in these environments include:

- advanced warning systems for natural hazards for people working within these environments
- using UAVs to inspect sites hazardous sites
- slope stability and rockfall monitoring systems in high-risk locations.

8.2.5 Smarter traffic management

While traffic management around planned activities was identified by stakeholders as an area that is generally done well, the Google GPS case study demonstrated some methods for monitoring traffic conditions around TMPs that could enhance current practices. This information can be used to automatically generate alerts and adjust traffic management strategies to suit current or expected conditions (see section 7.2.1 for a more detailed list of opportunities in this area).

8.2.6 Internet of things

Improved and expanded communication networks present one of the greatest opportunities for unlocking new real-time technology applications in the future. This includes the expansion of mobile networks to cover much of the state highway network and the development of LPWAN networks that support IoT devices and platforms. The proliferation of low-cost sensors and communication systems will create new opportunities for real-time monitoring of assets through IoT that were previously too difficult or too expensive to undertake.

8.2.7 Autonomous vehicles and connected vehicles

Real-time data generated by autonomous and connected vehicles could provide rich insights into how networks are performing and the condition of assets. These vehicles are equipped with multiple sensors that could detect many variables about the car, the road and the surrounding environment. Beyond the theoretical use for this data, it is difficult to predict when this type of application will become available and how it will be shared in the future.

8.2.8 Making better use of existing data sources

Many stakeholders alluded to existing data sources and technologies in use across New Zealand that have not been utilised to their full potential, including both real-time and non-real-time applications. It was not possible, within the scope of this research, to explore this issue in detail beyond appendix A, which lists all known real-time technology applications in New Zealand. There is an opportunity for further research to investigate where the problems are and identify methods for making more use of these. These methods could include:

- opening up data sources not currently available beyond the application it was developed from, to convert it into a standard format
- undertaking advanced analytics and developing real-time algorithms, for example this may include combining real-time and historic datasets to understand how different current conditions are to expected conditions
- improve how the data or application is made available to end-users, for example by making it available through an API that allows developers to build custom alerts/notifications and web applications
- in instances where the data is not being used due to uncertainty around quality, undertake testing and validation to confirm how useful it might be, and whether it is possible to quantify the level of uncertainty
- where possible, make data openly available to enable external users and developers to access it.

8.3 Real-time challenges

While real-time technologies provide new opportunities for asset and network management, they also come with challenges to ensure they can be used effectively and appropriately. The major challenges to the use of real-time technology and data are listed below. A risk register is presented in sections 8.3.1 to 8.3.5 and table 8.2 to capture the risks associated with the application of real-time technologies.

8.3.1 Large real-time datasets

Real-time datasets are often big datasets which can be used to provide a rich source of information on network and asset performance. This presents challenges across the spectrum of data capture, analysis, transfer and the visualisation of outputs, particularly when considering traditional approaches to data processing. Another challenge is that there is so much data it is not always clear exactly how it can be used.

Handling big, real-time datasets is a specialist area. There are several software solutions and platforms especially designed to handle this type of data. Techniques such as machine learning, regression analysis and algorithms can be applied to make sense of the data. There are also many software service providers who specialise in setting up big data analytics and visualisation platforms, and it is recommended that specialist advice is sought when considering applications relying on large real-time datasets.

8.3.2 Competing/multiple platforms and products

Many stakeholders noted the prevalence of different platforms and products essentially trying to solve the same problem, for example the use of Bluetooth and GPS datasets to understand real-time traffic conditions. Another example is the LPWAN IoT networks being delivered by four different providers, each with a similar range (particularly in rural areas) but with slightly different product offerings.

The challenge with different platforms and products is the difficulty in 'picking a winner', that is which of the platforms of products will last into the future versus those that become outmoded. This challenge is exacerbated by the potential for RCAs and contractors to apply these technologies in different ways.

There is no easy way to deal with this challenge. One approach is to consider the compatibility and flexibility of the technology. This can be achieved by ensuring the technology (whether it be sensor, communication network or visualisation output) can be integrated across a common platform or standard.

8.3.3 Automation and reliance on technology

Throughout the stakeholder engagement and workshops, it was noted that despite many highly intelligent real-time applications already being used, there is still a need for human input to understand, check and respond to what these systems are displaying. Examples include monitoring systems for tunnels, weather activated speed limits and the use of GPS data.

There is a risk in allowing data and algorithms to make isolated decisions about how the network functions. Real-time technologies should support existing decision systems and human knowledge, not replace them. Using real-time technologies, particularly those that are critical to the operation of assets or networks, raises several challenges for human operators, including:

- being bombarded with too much information and having to decide what is relevant and useful
- systems that are prone to error by over-reporting or under-reporting incidents (which will be ignored if they cannot be trusted)
- the need for continuous power supplies and fail-safe communication systems for critical systems.

Solutions to these challenges include:

- implementing software design approaches that put the needs of human operators first. Design thinking methods, for example, involve interviewing end users and observing how they work to inform how the product is delivered

- being able to adjust algorithms and trigger thresholds to ensure they are accurately reporting the events or activity in which they were intended to monitor
- using other methods of validation to check what the real-time system is reporting, for example using CCTV to examine why a rockfall alert has been issued
- applying measures of confidence to datasets or reports to help understand whether the information or reports can be trusted
- error reporting, in some form, when a system has failed, for example due to a lack of power or communications.

8.3.4 Expertise

Creating systems that integrate real-time technologies requires specialist knowledge and expertise that traditionally may not be considered within the realm of asset and network management. Specific knowledge areas include:

- internet of things
- big data/data science
- software design and delivery methodologies
- communications
- geospatial/location analytics.

These knowledge areas need to be supported with a practical understanding of asset management or network management. In the ITS and IoT industries, there is a recognised skill shortage (Ministry of Transport 2014; New Zealand IoT Alliance 2017), as well as a wider demand for skilled IT professionals. Government initiatives such as investment in education should help address this challenge in the longer term. In the meantime, knowledge sharing platforms such as industry forums and conferences can help to disseminate information on emerging technologies and the types of applications being developed in New Zealand and further afield.

8.3.5 Communications

Incomplete communication networks, particularly mobile networks, are a major limiter for using real-time technologies in rural areas. However, the emergence of new and expanded communication networks presents an opportunity to reconsider connectivity as a constraint to the use of real-time technology over the next few years. Initiatives underway that will improve rural communication networks include:

- the government's mobile black spot fund, which was recently expanded to include new coverage for around 1,000 kilometres of state highway (Crown Fibre Holdings 2017b)
- new and expanding IoT LPWAN communication networks, although it is expected that the rollout of these networks will primarily target urban areas initially.

These networks raise the possibility of rolling out real-time applications to locations once thought to be too remote and too difficult to service.

8.3.6 Risk assessment

Throughout this research many risks associated with real-time technologies and data were identified, particularly in relation to the challenges identified in sections 8.3.1 to 8.3.5 above. Table 8.2 sets out all these risks and summarises options for mitigation measures.

Table 8.2 Risk summary

Risk	Implications	Mitigation measures
Real-time datasets, particularly big data cannot be handled by traditional data capture, communication, analytical and visualisation platforms.	Limits on storage, communications and processing power reduce the potential applications for the data. Performance is reduced.	Use appropriate software products and platforms to suit the data source. Ensure there is sufficient expertise to implement big-data solutions.
Competing technologies and parallel development of similar applications. Applications developed by regions or different contractors do not align with a nationally consistent approach.	Risk of picking the 'wrong' platform and being locked into using it. Prevents a nationally consistent approach or clear common purpose to data collection and information sharing.	Choose technologies that use a common or standard platform for integration.
Data users (eg TOCs) being bombarded with too much information or having to use lots of different applications to meet information needs.	Data is ignored by users because there are too many other demands for their attention.	User-centred design of software applications.
Data users do not understand the quality of real-time data and whether to trust it. Real-time technologies under-report or over-report incidents or events.	Data is ignored because it cannot be trusted	Use additional methods of verification (eg CCTV) Validate outputs against other datasets (eg historic data) to see how accurate it is. Develop measures of confidence to report accuracy. Refine underlying algorithms or trigger levels to improve accuracy of outputs.
Power or communications failure (for critical real-time applications).	Data end user does not know that a system is in error state and cannot be relied upon.	Back-up power sources and communication systems. Error reporting (for users) when systems fail.
Lack of expertise to develop real-time applications	Applications poorly scoped, developed and implemented. RCAs and contractors miss opportunities to leverage new technologies.	Skills development initiatives across the transport and IT sectors. Conferences and forums encourage knowledge sharing.
Lack of communication coverage	Remote areas of New Zealand have poor mobile coverage reducing the coverage of real-time technologies.	Mobile black spot fund will see the expansion of mobile coverage across remote state highways and tourist hotspots.
Privacy	Positioning data allows for people to have their movements tracked. Technologies such as UAVS have the potential to breach privacy.	Privacy developed into applications at the outset, not as an afterthought. Refer to NZ Transport Agency (2016) *State highway operating manual* and follow Civil Aviation Authority rules for the use of UAVs.

9 Conclusions and recommendations

This report explores the opportunities and challenges of real-time technology and data in supporting network and asset management activities. This section discusses the key conclusions from the research and presents a summary of recommendations for further research.

9.1 Conclusions

The research identified a wide range of real-time technology sensors and applications in New Zealand. These are outlined in more detail in the literature review and in the stakeholder feedback. The range of applications in use is very broad and constantly developing, therefore it was not possible within the scope of this research to explore each individual application in detail. Where relevant, however, specific examples of different applications have been used to demonstrate potential opportunities and challenges facing the use of real-time technologies.

To assist in exploring potential applications of real-time technologies against the needs of network and asset managers, a framework of six activity areas was developed as follows:

- detecting and responding to network incidents
- managing planned events
- monitoring weather impacts
- managing hazards
- asset and site surveying
- structural asset monitoring.

It was found that not all activities have the same level of need for real-time information. In asset management, real-time data is essential for monitoring the condition of critical assets such as tunnels and certain bridges; however, there is value in using technologies such as LIDAR scanning, UAVs and continuous monitoring systems to support asset inspections and provide a richer dataset to inform asset maintenance and renewal programmes. The demand for real-time information for network management was much higher than for asset management alone, and several opportunities in this area were identified in the research.

Chapter 7 explores two different real-time applications in detail, the first being the use of sensor technologies to detect hazards as part of NCTIR’s rebuild of the rail and road networks along the Kaikoura Coast. The second case study explores the use of Google GPS data and advanced real-time data analytics to monitor congestion around planned works and to detect unplanned incidents on road networks.

The findings from the literature review, stakeholder consultation and workshop, and the case studies were collated by identifying strategic opportunities and challenges for developing real-time applications. In summary, the opportunities include:

- improving the speed at which incidents are identified
- exploring the use of predictive real-time modelling to understand the impact of incidents on the wider road network
- improving the detection of defects and hazards
- keeping people safe in high-risk locations

- smarter traffic management around planned events
- emerging opportunities associated with the IoT and autonomous vehicles
- making better use of existing data sources and technologies.

Challenges associated with real-time technologies include:

- handling ‘big’ real-time datasets
- the range of platforms and products in development and diverging approaches undertaken by different contractors and regions
- integrating the human element of interpreting the outputs of real-time systems
- the expertise required to design and implement real-time technologies
- the lack of communications coverage in rural areas.

A risk register has been presented in section 8.3 to detail the implications of these and other key risks and offer mitigation measures.

9.2 Recommendations

Specific recommendations for the implementation of this research and for future study are as follows:

1. Work with telecommunications and technology providers to keep informed of advances in technology and the latest available products and opportunities.
2. Given the fast-changing nature in which new technologies and applications are developed, RCAs, contractors and technology providers should use industry forums and conferences as a means of sharing real-time applications, including future opportunities and lessons learned.
3. Undertake a detailed stocktake of data sources and technologies in New Zealand, identifying opportunities to extract greater value from them. This may include:
    a. identifying data sources which are ‘locked’ into proprietary systems and explore methods for opening this up
    b. undertaking advanced analytics, which could include combining different types of data in innovative ways to provide new insights
    c. improve how the data or application is made available to end-users
    d. improve understanding of the quality of the data to determine how useful it is for decision-making purposes
    e. making data openly available.
4. Seek specialist advice when considering applications that generate or rely on large real-time datasets. Depending on the project, this may include specialists in the fields of big data, IoT, software design and delivery, communications and location analytics.

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Appendix A: Real- time technologies identified by stakeholders

Table A.1 Technologies for detecting and managing network incidents and planned events

Technology	Users	Use/activity	Application
Bluetooth	TOCs, customers	Travel times between fixed locations Journey times, delay	New Zealand (permanent and temporary installations) VMS, Drivelive Addinsight (used internationally) – Bluetooth sensors also act as broadcast beacons (virtual VMS)
CCTV and video analytics	TOCs	Identify stopped vehicles in tunnels, wrong way drivers, smoke, pedestrian and cycle traffic Traffic data (volume/speed/occupancy)	New Zealand, mainly Auckland and Tunnels
OptaSense fibre (distributed acoustic sensing)	RCAs, TOCs	Traffic volumes, journey times and incident detection	Auckland
GPS/GNSS (Google, EROAD)	TOCs, contractors	Journey times, fleet management, vehicle speed	Network performance and service level targets
TREIS/NIEMS	TOCs, contractors, RCAs	Information integration and communication	New Zealand wide
Radar	RCAs, TOCs	Monitoring multiple lanes of traffic (volumes and speeds)	Used internationally
Telematics datasets	TOCS, contractors	Location of nearest vehicle to incident, vehicle redirection. Fleet management	New Zealand ad hoc
SMART motorways applications	TOCs	Continuous count traffic data	Auckland and Wellington

Table A.2 Technologies for monitoring weather impacts

Technology	Users	Use/activity	Application
Weather activated variable speed limits	Customers	Visibility, weather conditions	State Highway 29 over the Kaimai Ranges in Bay of Plenty.
Roadside weather stations	TOCs, RCAs, contractors	Measuring wind, air temperature, humidity, rainfall, water film on roads, chemicals and freezing points	New Zealand wide (where sensors are located), provided by MetService
Vehicle-mounted weather stations	Contractors, Metservice	Weather variables including air temperature, road surface temperature, photos of road condition	Temperature data and photographs transmitted in real-time where coverage allows. Assists in decision making and the timely delivery of winter maintenance services.

Technology	Users	Use/activity	Application
Dynamic route forecasting	RCAs, TOCs	Corridor volumes, base course depth and other indicators at up to 30 m resolution	Trialled on Desert Road, now covers 2000 km of the state highway network and will be extended to the state highway network at 5 km intervals in the near future.
Thermal mapping	Contractors, customers	Road surface temperatures, application of de-icing agents, customer messaging	New Zealand wide, provided by MetService

Table A.3 Technologies for managing hazards

Technology	Users	Use/activity	Application
CCTV and video analytics	NCTIR	Observe high risk sites for rockfall	Rebuild of road and rail along Kaikoura Coast
Rain gauges	RCAs, regional councils and customers	Monitor water levels within rivers, streams and culverts	Used throughout New Zealand to inform decision-making processes regarding the status of the network. This information is used both pre-trip and on-trip to inform drivers to plan their journeys appropriately.
Road 'drop' sensors	Contractors, RCAs	Indicate movement in the pavement structure	New Zealand West Coast
Slope monitoring equipment (tilt meters and piezometers)	Contractors, RCAs	Ground water monitoring, soil movement.	New Zealand West Coast, but have subsequently been removed due to false alarms
Roadroid	RCAs, freight operators	Defect management, measure surface roughness	New Zealand One Road Controlling Authority has leveraged this technology together with partnership opportunities with freight operators on their network to secure 80% coverage of their network.

Table A.4 Technologies for asset and site surveying

Technology	Users	Use/activity	Application
Truwitness smart phone map-based video streaming	Contractors, TOC	Mobile CCTV stream	Unknown
Unmanned aerial vehicle (UAV)	RCAs, contractors	Crash investigation, scour and erosion monitoring with 3D Cam virtualisation, access to difficult areas	Auckland for crash investigation, South Island for scour and erosion monitoring
LIDAR	Contractors, RCAs	Crash investigation, scour and erosion monitoring,	Limited use in New Zealand

Table A.5 Technologies for structural asset monitoring

Technology	Users	Use/activity	Application
Weigh-in-motion	RCAs	Vehicle speed, volume, axle count, axle weight and vehicle length	Installed at relatively few sites in New Zealand. A 'weigh right trial' is currently being undertaken on State Highway 1 at Glasnevin (North Canterbury) to identify overweight vehicles and direct them to a weight bridge for compliance checking
CCTV and video analytics	TOCs	Identify stopped vehicles in tunnels, wrong way drivers, smoke, pedestrian and cycle traffic. Traffic data (volume/speed/ occupancy)	New Zealand, mainly Auckland and tunnels
Over-height vehicle detection	RCAs, TOCs	Detect over height vehicles and trigger alert, VMS	Deployed at most tunnels in New Zealand.
SMART motorways applications	TOCs	Continuous count traffic data	Auckland and Wellington

Appendix B: Glossary

ANPR	automated number plate recognition
API	application programming interface
BOTDR	Brillouin optical time domain reflector
CCTV	closed circuit television
DAS	distributed acoustic sensing
DMI	distance measuring instrument
GB-SAR	ground based interferometric synthetic aperture radar
GNSS	global navigation satellite system
GPS	global positioning system
IMU	inertial measurement unit
IoT	internet of things
IRI	International Roughness Index
ITS	intelligent transport systems
LIDAR	light detection and ranging
LPWAN	low powered wide area network
MAC	media access control
MEMS	micro electro-mechanical systems
NCTIR	North Canterbury Transport Infrastructure Recovery
NIEMS	National Incident and Event Management System
NOC	network outcome contract
RCA	road controlling authority
SCATS	Sydney Co-Ordinated Adaptive Traffic System
SHIP	State Highway Investment Proposal
TMP	traffic management plan
TOC	transport operations centre
Transport Agency	New Zealand Transport Agency
TREIS	Traffic Road Event Information System
UAV	unmanned aerial vehicles
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VMS	variable message signs
WAVSL	weather activated variable speed limit
WiM	weigh-in-motion