Identify the uses of emerging sources of digital data to assess the efficiency of the state highway network

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An important note for the reader

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Executive summary

This report assesses the potential use of emerging digital technologies and data sources in monitoring the performance of the New Zealand state highway network. The objectives of this research were to:

- review the availability and current applications of digital data for road network monitoring in New Zealand and overseas
- determine the extent to which digital data can be used to inform useful state highway network monitoring indicators which support transport planning, transport optimisation initiatives, road safety and asset management in New Zealand
- develop a geographic information system (GIS) based reporting tool, fed by a database of raw digital data and the nationwide state highway network, to test the application of digital data to support identified network monitoring indicators
- deliver a proof-of-concept study demonstrating how the front-end reporting tool can support transport planning, transport optimisation initiatives, road safety and asset management.
- build a business case for sourcing digital data from third party suppliers to support the front-end reporting tool's data requirements.

A review of emerging digital technologies and data sources was undertaken within the context of intelligent transport systems. To reduce the scope of the research, the project team, in conjunction with the project steering group, narrowed down the emerging technologies to be reviewed to Bluetooth, global positioning systems (GPS), infrared, mobile, laser, weigh-in-motion and microwave technologies.

The technology review found that only six of these technologies were in use in New Zealand, and only four (GPS, Bluetooth, mobile and weigh-in-motion) could feasibly provide data from which network indicators could be generated. The project team contacted all the data suppliers of these technologies in New Zealand to determine the availability, quality and type of data available, and to obtain sample data from which a proof of concept could be developed.

A review of the literature on transport indicator frameworks was undertaken to understand existing transport monitoring activities and to identify a best practice set of indicators. The review identified a number of gaps in New Zealand's current monitoring frameworks, and concurred with a recently published NZ Transport Agency research report that presented a new best practice indicator framework centred on the concept of 'wellbeing' (Denne et al 2013). This framework was adopted as the initial framework for assessing the usefulness of the identified digital data sources.

Once the technologies and potential indicators were identified, each indicator was tested against the sample data to determine whether it was feasible to use this data to support the indicators identified. In addition to a feasibility assessment, a sensibility check was undertaken to ensure the data added value to what was currently available. Primary indicators (the raw outputs from the data supplier) were distinguished from secondary indicators, which require additional data inputs or processing to be generated. Primary indicators are speed and travel time (minimum, maximum, average and median), sample counts and statistical measures of speed or travel time (for example standard deviation and percentiles). The secondary indicators measure a suite of network performance and capability, cost, health and environment, activity and safety indicators.

The outcome of this identification and testing process was a concise list of transport monitoring indicators that could be generated from the data provided. An additional output was the conclusion that only GPS and

Bluetooth could provide useful data for generating indicators. The mobile data proved to be too coarse to be practical and privacy concerns limited the type of data that could be provided. With only six sites in New Zealand, weigh-in-motion data also proved to be too limited in scope to be useful at a network-wide level.

Further, extensive interrogation of the sample datasets was undertaken to determine the most appropriate methodology for generating the indicators. This included identifying and testing limitations, assumptions and additional data requirements. A number of recommendations were made, including the key recommendation that in order to provide meaningful and robust outputs, data sources should ideally be calculated to hourly periods, aggregated across a week or a month of data.

After establishing the methodology, a GIS-based proof-of-concept model was developed. This consisted of four different data sources (two GPS and two Bluetooth) covering four different road and mode environments, including both state highway and non-state highway road networks, rural and urban environments, and public transport modes. A detailed methodology and conceptual database framework is presented for the generation of centreline segments, the processing of digital data and the generation of the indicators. The datasets and indicators included in the proof-of-concept model are presented in the table below.

Summary of proof-of-concept datasets and indicators to be tested

Indicator		Waikato SH network (BT)	Auckland local roads (BT)	Wellington SH network (GPS)	Auckland PT (GPS)
NP1.1	Average travel time – private vehicle	Y	Y	Y	
NP1.2	Average speed – private vehicle	Y	Y	Y	
NP1.3	Average travel time – public transport				Y
NP1.4	Average speed – public transport				Y
NP2.1	Minutes delay per km – private vehicle	Y	Y	Y	
NP2.2	Minutes delay per km – public transport				Y
NP3.1	Standard deviation speed			Y	
NP3.2	15th percentile speed			Y	
NP3.3	85th percentile speed			Y	
NP4	Variation from speed limit	Y	Y	Y	
NP5	Estimated hourly volume	Y	Y		
HE1.1	Rate of emissions – CO	Y	Y		
HE1.2	Rate of emissions – N_2O				
HE1.3	Rate of emissions – PM_{10}				
HE1.4	Rate of emissions – VOC				
HE2	CO_2 emissions	Y	Y		
S1	VKT by star rating	Y			
A1	Vehicle kilometres travelled	Y	Y		
A2	Total freight tonne kilometres			Y	
C1.1	Cost per vehicle kilometres travelled	Y	Y		
C1.2	Total cost of travel				
C2.1	Cost per freight tonne kilometre			Y	
C2.2	Total cost of freight travel				

The proof-of-concept model successfully reported on all the indicators using the methodologies identified. The primary output of the proof-of-concept model was a GIS-based web viewer that displayed all the indicators identified. In addition to the web viewer, a number of further considerations were raised, including data validation and data quality requirements.

A number of risks and opportunities associated with the roll-out of the proof-of-concept model were identified through consultation and evaluated through a risk assessment process. In order to mitigate these risks, it is recommended that the NZ Transport Agency (the Transport Agency) undertake early engagement with suppliers and retain a flexible approach in contractual dealings, particularly in the start-up phase, while the performance indicators and model are being established. Overall, the assessment concluded that the majority of the risks were indeed manageable, and that there were significant opportunities to be realised by the Transport Agency in rolling out the model.

Discussion with suppliers has been overwhelmingly positive, with the majority of suppliers clearly stating that they are open and flexible to pricing and procurement models as long as privacy and commercial sensitivity matters are satisfactorily addressed. Given the supplier's interest and willingness to work with the Transport Agency in this emerging and competitive market, there is an excellent opportunity to build strong data-supply relationships with multiple suppliers.

The proof-of-concept model provides a common source from which a range of Transport Agency business units can be informed, and has been developed to share common elements with other Transport Agency geospatial tools and applications. Thus, there is the opportunity to standardise data sources, achieve synergies between the model and other Transport Agency initiatives such as the Transport Data Warehouse, and support the Transport Agency's desire to centralise geospatial resources. This has the potential to deliver benefits for subsequent analysis and reporting across a range of business units of the Transport Agency while maintaining flexibility so the model can continue to develop to meet future needs.

With regard to the implementation of this research, it is recommended that the Transport Agency:

- actively keeps abreast of new technologies and applications that will arise in the future
- considers the indicator framework and GIS viewer presented in this report as a starting point for a national-level state highway performance monitoring portal
- undertakes early engagement with suppliers and retains a flexible approach in contractual dealings, particularly in the start-up phase, while the performance indicators and model are being established
- negotiates contracts with potential suppliers to allow sufficient flexibility to fine tune the model and the specification for the data stream
- explores synergies between this research and other emerging Transport Agency initiatives such as the Transport Data Warehouse
- takes the opportunity to integrate existing geospatial data and resources as far as practicable with future geospatial development.

It is further recommended that to build upon this research, further study be undertaken to:

- investigate the potential of crowd-sourcing applications (eg mobile opt-in applications) to 'fill the gap' for measures, such as throughput, which cannot be generated from the technologies covered in this research project
- consider data integration or fusion across emerging data sources in order to correlate data as far as possible across data sets

- further investigate data quality issues to consider the accuracy of the base data and understand the impact of data quality on long-term trending data, and the sensitivity of data across different times of day and geographic areas
- scope the data retention and data storage requirements, enabling long term trending which in turn would support key business decision making.

One of the stated objectives of the research was to determine the extent to which emerging technologies could be used to inform useful state highway network monitoring indicators. Subsequently the recommendations in this report have been directed at the NZ Transport Agency as the road controlling authority tasked with managing and operating this key asset. The outcomes of the research will, however, also be of interest to other road controlling authorities, as they are similarly applicable to monitoring the performance of non-state highway road networks.

Abstract

Digital data from emerging sources such as GPS, Bluetooth and weigh-in-motion is currently captured in New Zealand for a range of traffic monitoring purposes. This research project was undertaken to provide guidance on what capacity exists to assess the performance of the state highway road network using these digital data sources.

This report summarises the background research, model development and delivery, and future opportunities to understand the performance of the state highway road network, both spatially and over time, using emerging digital data technologies.

This research initially explored how the various data sources could inform a range of network indicators covering private and public transport modes, safety, environment, activity and cost. A GIS-based proof-of-concept model was developed to demonstrate how currently available data sources could inform these indicators, which were then displayed in a web viewer that could be used to help the NZ Transport Agency measure the performance of the state highway network.

This report also includes a business-case for the roll-out of the proof-of-concept model to a nationwide-level, including an assessment of opportunities and risks, and recommendations for engaging with third party data suppliers.

1 Introducton

The NZ Transport Agency (the Transport Agency) contracted Abley Transportation Consultants, supported by URS New Zealand Limited, to determine what capacity exists to assess the performance of the New Zealand state highway (SH) road network through the use of new technology and emerging sources of digital data.

The objectives of this research were to:

- review the availability and current applications of digital data for road network monitoring in New Zealand and overseas
- determine the extent to which digital data can be used to inform useful SH network monitoring indicators which support transport planning, transport optimisation initiatives, road safety and asset management in New Zealand
- develop a geographic information system (GIS) based reporting tool, fed by a database of raw digital data and the nationwide SH network, to test the application of digital data to support identified network monitoring indicators
- deliver a proof-of-concept study demonstrating how the front-end reporting tool can support transport planning, transport optimisation initiatives, road safety and asset management
- build a business case for sourcing digital data from third party suppliers to support the front end reporting tool's data requirements.

The research underpinning this report was undertaken during 2013–2014 and involved six phases of work, starting from an initial technology and literature review and finishing with the development of the business case. Each phase of the project was separately reported to the Project Steering Group. This report therefore presents both an overview of the research process as it was developed, and the outputs (including recommendations) that were generated.

This research built on the recently completed Transport Agency research project (Denne et al 2013) which presented a best practice transport monitoring framework by identifying how emerging digital data sources (such as global positioning systems (GPS) and Bluetooth detection technologies) could be used to sensibly and efficiently report on road network performance.

1.1 Report structure

The report is organised as follows.

Chapter 2 introduces the high-level context of this research with respect to the emergence of intelligent transport systems (ITS) in New Zealand and overseas. The different types of emerging digital data technologies are identified and discussed.

Chapter 3 explores ITS and the emerging technologies in more detail, and is supplemented by an appendix which contains the findings of an extensive ITS and digital data literature review. The range of technologies, digital data sources and applications presently available in New Zealand are identified in this chapter.

Chapter 4 presents the findings of the literature review regarding transport indicator frameworks. The output of this chapter is an initial set of best practice indicators against which the emerging digital data will be tested.

Chapter 5 sets out a conceptual framework for developing the indicators. The initial best practice indicators are tested against sample data sets to determine whether they can feasibly be evaluated. The output of this chapter is the final set of indicators to be developed through the proof-of-concept model.

Chapter 6 explores alternative methodologies for producing the indicators from the data provided and provides recommendations regarding additional data requirements, including any corresponding assumptions and limitations of application.

Chapter 7 introduces the proof-of-concept model and database framework. This chapter introduces the four sub-project areas corresponding to sample data sets sourced from commercial data suppliers, and includes a detailed GIS workflow for generating the output indicators.

Chapter 8 reports on the proof-of-concept delivery, identifying strengths and weaknesses from the implementation of the methodology.

Chapter 9 develops the business case for the roll-out of the proof-of-concept model nationwide. This includes the identification and assessment of risks, and guidelines for the future engagement of digital data suppliers.

Chapters 10 and 11 present conclusions and recommendations.

2 Background

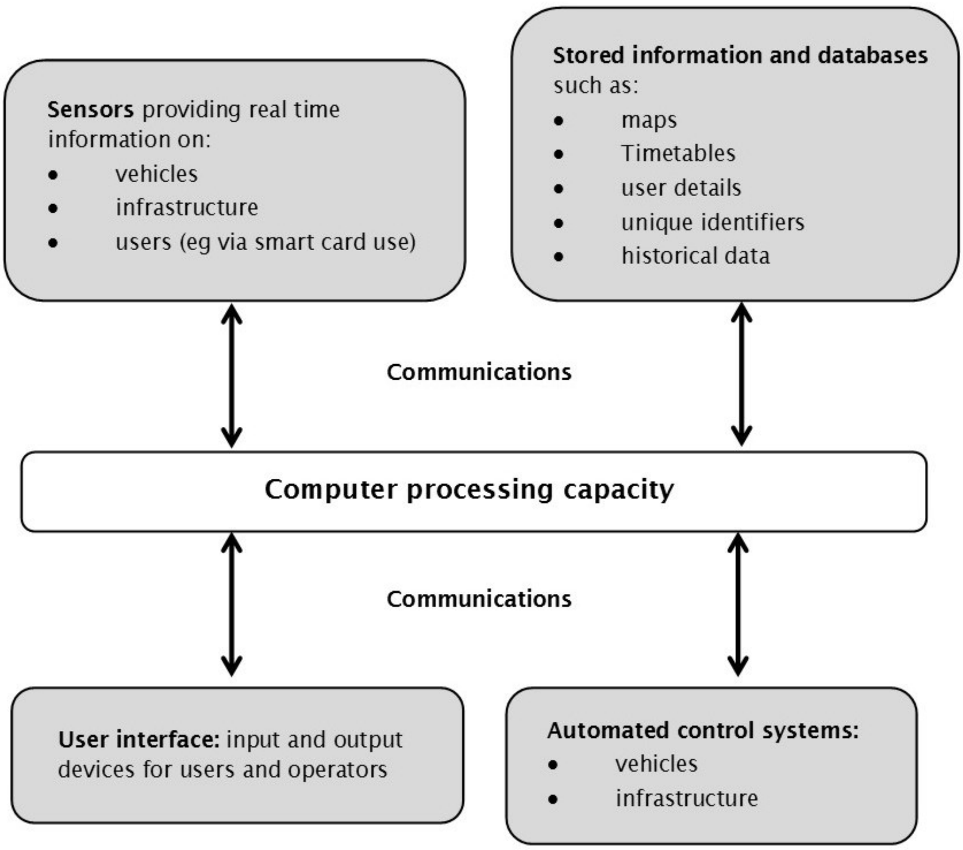
This chapter explores the current role of ITS in New Zealand and overseas, and introduces the emerging digital data sources available in New Zealand that could be incorporated into the proof-of-concept model developed in this research project. These findings result in a summary of emerging data sources available to the Transport Agency to assist in measuring the performance of the SH network.

2.1 Intelligent transport systems (ITS)

Until recently, real-time information on traffic conditions was collected solely by road controlling authorities and not by road users themselves. Through the proliferation of in-vehicle satellite navigation systems and location systems associated with 'intelligent' devices, road network operating conditions such as vehicle speeds, delays and congestion can now be measured and reported.

ITS apply modern computing processing capabilities and modern advances in technology (such as automated control systems, sensors, transportation databases and other input/output devices) to help solve transportation problems, as shown schematically in figure 2.1 (adapted from MoT 2013a). ITS support the better utilisation of existing road network assets. Hence, ITS can be a cost-effective approach to monitor, understand and manage transportation problems.

Figure 2.1 Components of a typical intelligent transport system



The term 'intelligent transport systems' has evolved from telematics, the integrated use of telecommunications and informatics. The origin of ITS stems from the use of emerging technologies in a variety of practical applications. Initially, control and monitoring technologies were used in combination with hardware such as traffic signals. In the last 20 years, advances in technology and electronics have enabled applications for road and rail travel to develop. Perhaps the widest use of technology has been for the dissemination of information to road users, which has expanded in the last 5 to 10 years as mobile communications become commonplace (FHA 2011).

Digital data to support ITS is collected by a range of technologies including in-road traffic detectors, GPS and Bluetooth. As well as data collection, ITS incorporate the provision of timely travel information to transport authorities to support network management, and to road users though media such as variable messaging signs (VMS) and in-vehicle communication systems. Wider benefits of ITS include economic, safety and environmental benefits and improvements in travel experience though reduced congestion, improved road safety and reduced fuel consumption.

2.2 Emerging ITS data collection technology

Although ITS encompass a range of systems and applications, the objective of this research project was to focus on data collection technologies, which can be categorised as ‘conventional’ or ‘emerging’ technology. An ‘emerging’ technology is defined as a state-of-the-art technology that is either a new source of data to support highway monitoring, or a relatively recent technology for which the full potential of the application to support highway monitoring has not been fully explored.

The categorisation of ITS technology summarised in table 2.1 was undertaken in consultation with the Project Steering Group and only those technologies identified as ‘emerging’ were investigated further. The emerging technologies identified in table 2.1 are discussed in more detail below.

Table 2.1 Conventional and emerging digital data technologies

Conventional technologies	Emerging technologies
• inductive loops • infrared radar • manual counts • ultrasonic detector • pneumatic tube • video imaging • piezoelectric cable	• Bluetooth • GPS • infrared • mobile • laser • weigh-in-motion • microwave

2.2.1 Bluetooth

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 ‘MAC’ address which can be used to identify that particular device. Bluetooth detectors placed at the roadside can detect Bluetooth devices in passing vehicles as far as 100m away.

In ITS applications, 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.

2.2.2 GPS and GNSS

Global navigation satellite systems (GNSS) use satellite constellations and ground-based receivers to determine geographical locations. GNSS systems include the American GPS and Russian GLONASS satellites. 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 of the term '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.

2.2.3 Infrared

Infrared technologies use either passive or active infrared detectors to detect vehicle presence and speed. Passive detectors detect infrared radiation emitted from vehicles or other moving objects, while active detectors emit and detect infrared radiation reflected from vehicles that pass through an infrared beam. Some detection technologies, for example the infrared traffic logger (TIRTL), can also record vehicle classifications by recording and interpreting wheel configurations (CEOS Industrial 2009).

2.2.4 Mobile

Mobile-enabled devices such as smart phones operate on cellular networks, providing voice, text message and data services to users. Through cellular networks such as the global system for mobile communications (GSM) and the universal mobile telecommunications system (UMTS), the movement of these devices in the vicinity of cell phone stations (towers) can be tracked. It is possible that mobile device tracking data can be collected and filtered to provide data on travel time, speed and people throughput for a range of transport modes. Alternatively, opt-in applications (apps) for smart phones can use a combination of GPS and mobile phone network data to provide travel and location data.

2.2.5 Microwave

Microwave-enabled sensors directed at vehicle lanes send and receive microwave energy, which can then be used to detect individual vehicles and vehicle speeds. Microwave sensors can also detect vehicle length, so this technology is often used as part of electronic tolling, including the management of toll pricing and payment.

2.2.6 Laser

Laser sensors can be applied in a number of ways to monitor traffic movement. Roadside or overhead laser scanning technology can be used to count, classify and determine vehicle classifications (Komrakov et al 2011). Roadside laser sensors are also commonly used to detect vehicle speed for enforcement purposes.

2.2.7 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.

3 Technology review

The research team investigated the New Zealand applications of emerging technologies to ascertain the suitability, feasibility and availability of each for inclusion in this research. This review included identifying ITS and emerging digital data technology applications from around the world.

The technology review produced a wealth of information, ranging from technology and supplier datasheets through to research reports and practical applications, which was initially difficult to manage. The table presented in appendix A contains a summary of the references identified, grouped broadly by geographical region (Australia/New Zealand, Asia, Europe and USA). The table was developed to allow a user to quickly determine the relevant information that each source contained. Several key information parameters, relating to the information covered in each literature source, were selected to be shown on the table. These parameters included publication details, digital data technologies and network performance indicators. Data technologies were further categorised as either emerging or conventional. A summary of the information contained in each source is also provided.

Rather than reiterate the considerable detail captured in appendix A, this section provides a high-level overview of ITS overseas and in New Zealand in sections 3.1 and 3.2 respectively. Sources of digital data in New Zealand are discussed in section 3.3; however, it has been necessary to anonymise the specific data sources to meet the principles by which the Transport Agency commissions research.

3.1 ITS overseas

In most developed countries with recurrent congestion problems, ITS are seen as cost-effective tools relieving congestion and providing information when non-normal conditions occur (FHA 2012). A further attraction of ITS is that they can usually be applied quickly and benefits are continuous, perhaps accelerating over time as traffic levels grow. With recent advances in communications technology, which is becoming progressively cheaper and more accurate (eg measuring flow and speed across multiple lanes of traffic), the application of ITS is not as expensive as it was five years ago.

In general, the application and deployment of ITS in the USA, European and Asian countries is considered more mature than elsewhere in the world. Much of this is due to economies of scale, the availability of a prioritised funding source, a focus on the measurement of benefits and lessons learned, and a greater degree of information dissemination (FHA 2012). This is evident by the quantum of literature on digital data and applications to the transportation network (see appendix A).

In the USA, ITS development typically follows the federal government's lead. Various federal organisations have continued to develop, coordinate and integrate the geospatial technologies into the transportation (and numerous other) sectors.

The technology review found that the use of ITS does not deliver benefits to the same level as some other major capital projects, but as the cost of supplying and installing ITS is relatively small, its provision will remain attractive in most circumstances, particularly for congestion management.

3.2 ITS in New Zealand

The Transport Agency builds, manages and operates New Zealand's SH network, which is of national and strategic importance for keeping people and goods moving. The Transport Agency operates three joint traffic operation centres (JTOC), which are located at Smales Farm on Auckland's North Shore, at

Johnsonville in Wellington, and the most recently established Christchurch Traffic Operations Centre in Christchurch. These centres play a vital role in enhancing road users' day-to-day travel experience by managing traffic and incidents on the road network.

The Auckland JTOC is a partnership with Auckland Transport and focuses on reducing Auckland's congestion issues on motorways and arterials by integrating region-wide traffic management. The Wellington JTOC's principal aim is to provide timely and accurate traveller information using the Transport Agency's network of advanced traffic management systems and VMS across the lower North Island.

JTOCs are working closely with the Transport Agency to develop the advanced real-time traffic information system to deliver journey time information along key arterial routes (Auckland Transport 2011). To provide timely and accurate information the JTOCs gather data from different sources such as road sensors, closed circuit television (CCTV) cameras, police incident reports and feedback received directly from contractors and the public via an 0800 phone number. Other tools used by the JTOCs include the coordination of traffic signals, VMS, the traffic road environment information system (TREIS) and InfoConnect.

Other road controlling authorities, including Hamilton city and Tauranga city, also have their own traffic management centres. Tauranga city, in particular, has an extensive ITS monitoring network.

In New Zealand urban areas, mainly through the use of the Sydney coordinated adaptive traffic system the provision of ITS is evident. Ancillary technologies such as car park monitoring and signage through VMS are not as well developed. On interurban routes, the use of ITS is not extensive and there is plenty of scope to raise the use and profile of ITS for these routes in New Zealand. New Zealand is increasingly applying emerging technologies to support traffic management, control and traffic data collection. Bluetooth and GPS in particular are used to obtain and retrieve real-time information and are available nationwide. Road users in New Zealand are able to take advantage of live traffic updates using GPS data sources via the internet and mobile devices.

3.2.1 Digital data collected in New Zealand

The research team reviewed the current status of the New Zealand digital data marketplace to determine which emerging technologies are currently being applied in New Zealand, and documented the various applications of each, as presented in table 3.1.

Table 3.1 Emerging technology applications in New Zealand

Technology	Application in NZ
Bluetooth	Bluetooth sensors supply travel-time data for the NZ Transport Agency, MoT and local authorities. Bluetooth sensor networks are installed in most of New Zealand's largest cities and along SH corridors in Auckland and Waikato.
GPS	GPS data is collected to provide near real-time information for transport managers and road users, and to monitor the performance of public transport services.
Infrared	Infrared detection technologies have been used for research purposes (eg Walton and Buchanan 2011), cycle counting (Land Transport NZ 2008) and at some telemetry sites (NZ Transport Agency 2004a).
Mobile	Mobile activity (calls, text messaging and data usage) data is collected nationwide, but is not currently used for traffic management or monitoring purposes.
Laser	The New Zealand Police use both handheld and fixed laser devices to measure vehicle speed for enforcement purposes.
Weigh-in-motion	Vehicle count and weight data is collected at six locations on the SH network (Auckland, Waikato, Bay of Plenty, Gisborne, Hawke's Bay and Canterbury).

The technology review found that six of the seven emerging technologies initially identified in table 2.1 are currently used in New Zealand. The one technology not available is microwave technology, which is used overseas for electronic tolling booths. Some of the other emerging technologies identified in section 2.2 are also applied in New Zealand with limited coverage, for example WiM is only used at six locations and laser technology is used for speed enforcement. Enquiries with potential infrared and laser technology users revealed a lack of commercially available datasets that could be carried forward in this research.

From the initial technology review, four emerging technologies for which commercially available data could be sourced, were shortlisted for further investigation in this research project, namely:

- GPS technology
- Bluetooth technology
- mobile technology
- WiM technology.

3.3 Emerging digital data sources in New Zealand

The following sub-sections discuss potential sources of digital data from GPS, Bluetooth, WiM and mobile data suppliers. Throughout the course of the literature review and subsequent research, commercial data suppliers were contacted and information specific to their business operations was collected. This included the types of data collected, geographic coverage, data collection frequency, sample size, data use, format, service reliability, quality and accuracy. Sample data sets were sought from each supplier identified in the New Zealand marketplace.

3.3.1 GPS technology and applications

GPS technology is used in an increasingly diverse range of applications and is capable of gathering a variety of data. Four applications in use in New Zealand are:

- live traffic information accessible via internet or GPS navigation unit
- tracking of individual/fleet vehicles
- in-car navigation systems
- monitoring of public transport (PT).

3.3.1.1 Private and commercial transport

There are a number of GPS data suppliers in New Zealand collecting travel data from commercial and private vehicle fleets. The research team identified six suppliers with significant coverage both geographically and in terms of the quantity of data available. Some of the suppliers focus exclusively on collecting commercial data and others collect a mixture of commercial and private fleet data; however, there is a general bias towards commercial fleet data due to the nature of the industry. The majority of suppliers offer fleet management services for tracking individual vehicles and facilitate in-car navigation for users. Some also provide live traffic information via the internet and/or via GPS navigation devices.

Generally speaking, GPS data suppliers collect data from all public and private roads across New Zealand including the entire SH network, and data outputs are highly customisable to meet user needs whether they be public or private sector.

Almost invariably, data is post-processed by the data supplier to produce vehicle speeds and/or travel times between waypoints, which may be pre-defined by the end user or fixed based on the network data collection specifications of the individual data supplier. Most data suppliers archive data on key routes but the geographic and temporal extent of archiving varies considerably. Data is available in a variety of formats and there is a general willingness from data suppliers to be flexible in this regard. Most suppliers provide output data in spreadsheet form or as spatial data.

Data suppliers can provide speeds and/or travel times as minimum, maximum, median, percentile and averages between waypoints, and some suppliers also calculate standard deviations to measure the travel time or speed variability. This data is post-processed by the suppliers, and can be made commercially available in time intervals as fine as 15 minutes. Raw GPS data is not readily available which makes it difficult to independently audit the post-processed outputs.

Accuracy of the location data is excellent with some suppliers stating accuracy to within 3m. Spatial representation of traffic links (road centrelines) is available via MapInfo and ESRI shapefile format and relational attribute tables are available in spreadsheet format.

3.3.1.2 Public transport

Auckland Transport has installed GPS devices and automatic vehicle locators on all buses operating within the city to track the location of each vehicle and monitor any delays or early arrivals at bus stops. Whenever a bus travels past a ‘way point’ (specific bus stop) the signal from the automatic vehicle locator is detected and sent to a central server where the scheduled time of arrival at the bus stop is compared with the actual time of arrival to measure on-time reliability. The data is also used to display expected arrival times at bus stops where message boards are installed.

Greater Wellington Regional Council (GWRC) collects GPS data from public bus services to a similar level of detail. GPS devices are installed on the bus fleet and transmit data on the location and bearing of each vehicle at every waypoint and every 30 seconds. Currently data is collected on 80% of bus routes in the region. The GWRC primarily uses the data for transportation planning, and accuracy is measured to within 15m which is typical of most GPS technology. The GWRC verifies the reliability of the data by checking it against ticket information.

GPS units are fitted to all vehicles in the Christchurch bus fleet, with Environment Canterbury using the location data to track buses in real time. An estimated time of arrival is available via the internet, mobile applications, and via VMS and call boxes at bus stops. The estimated arrival times are based on historical data and do not reflect the level of congestion or impedance in the network at any given time. The times at which buses reach key stops is not specifically recorded to measure travel-time performance and needs considerable cleaning prior to issue.

3.3.2 Bluetooth technology

The research team identified two ITS providers who make use of Bluetooth sensors to gather traffic data using fixed detectors on both local and SH networks in New Zealand. Both suppliers specialise in collecting and providing network monitoring and traffic data, and are in the process of expanding the coverage of their networks. There are also multiple providers who collect data using portable Bluetooth detectors for one-off traffic monitoring on the road network.

Suppliers can report minimum, maximum, median, percentile and average travel times between each pair of Bluetooth detectors in a configurable interval which can be calculated as often as every minute. Sample size is dependent upon the number of Bluetooth devices in use and is generally considered to be increasing as more Bluetooth-enabled cars are entering the vehicle fleet. Suppliers stated that 15% to 18% of vehicles are currently recorded by detectors. The data can be used to provide information on travel time, travel-time reliability, seasonal variance in traffic and origin-destination flows.

The addition of WiFi sensors has the potential to further enhance the percentage of vehicles represented. While WiFi sensors are installed in some Bluetooth hardware in New Zealand, no data is currently collected from the detection of WiFi signals.

Bluetooth data is commercially available and can be provided in a spreadsheet format, and one supplier provides a web user interface or an open Webservices API to access data. Bluetooth technology provides a reliable service with at least 99.99% reliability of hardware, and battery backup systems in place to protect against short-term loss of power. Recording of vehicles is generally accurate to within 100m.

3.3.3 Mobile technology

There are a small number of participants in the New Zealand mobile marketplace; however, all mobile providers approached highlighted that mobile data is not readily or commercially available. This is primarily due to concerns about potential breaches in individual mobile users' privacy. Data is collected by some mobile companies pertaining to the nature and location of mobile activity (text messages, calls and internet usage) in the vicinity of mobile phone tower sites throughout New Zealand. The research team sourced a data sample from one supplier in this regard and this is considered further in chapter 5.

Mobile technology can also be used to identify the locations of mobile devices through triangulation of signals from mobile phone tower sites and therefore it is plausible that individual devices could be tracked as they travel throughout the transportation networks. To protect the privacy of individual users, resultant tracking data is not available; however, the potential emergence of opt-in tracking applications in the future is considered to be a possible source of useful data.

3.3.4 Weigh-in-motion technology

The Transport Agency operates WiM sites at six locations in New Zealand. The sites employ bending plate technology, with a metal plate installed on the carriageway surface hard wired to an electronics box which houses the equipment for data storage (NZ Transport Agency 2013a). The WiM sites are co-located with loops for recording vehicle counts and speeds.

Approximately 3 million vehicles were recorded to have travelled over the WiM sites in 2011 (NZ Transport Agency 2013a). Data gathered from these sites is used for a variety of purposes, including determination of the average equivalent standard axles for pavement design, load distribution for bridge design, network loading design and to assess the revenue from road user charges (RUCs). The data collected can be viewed in a spreadsheet format and is available through the Transport Agency's traffic monitoring system website.

A number of quality control measures are applied to WiM sites to ensure accurate measurements are taken. Weight measurements can be affected by the condition of the pavement; therefore, the pavement is periodically checked to ensure appropriate pavement condition is maintained. Calibration is carried out using vehicles of known axle weight and speed. Data is monitored for errors and deviation, with the resultant quality control ensuring gross vehicle weight measurements are accurate to within 10%. Each vehicle passing over a WiM station is recorded and the axle loading, number of axles, speed and time at which the vehicle passed over are recorded.

4 Transport indicator frameworks

A review of literature on transport indicator frameworks was undertaken to understand current transport monitoring frameworks in New Zealand and compare them with those used in other countries and jurisdictions. Literature on best practice for developing indicator frameworks is also addressed in this chapter. The outcome of the literature review was an initial set of indicators that was tested to confirm whether emerging data sources could be used in their calculation. The initial indicator set is listed at the end of this chapter (table 4.5).

4.1 New Zealand transport indicator frameworks

There are two key sets of transport indicators in New Zealand: the Transport Monitoring Indicator Framework (TMIF2), which reports against a large and varied range of transport activities; and the Transport Agency's result indicators, as reported in its *Statement of intent 2012–2015* (SoI), which assess the performance of the Transport Agency and the SH road network against government policy for road transport.

4.1.1 Transport Monitoring Indicator Framework version 2 (TMIF2)

The TMIF2 is published by Mot (2012a) and contains a large number of transport-sector indicators, categorised into the following sets:

- transport volume
- network reliability
- freight and the transport industry
- access to the transport system
- travel patterns
- transport safety and security
- public health effects of transport
- infrastructure and investment
- environmental impact of transport
- transport-related price indices.

The TMIF2 monitors trends over time, and is intended to be used by all transport sector groups as a tool for informing and evaluating transport-related policies and strategies. Indicators are updated by the Ministry on an on-going basis through their website as the data becomes available. Not all indicators are supported by data at this time, although it is the intention of the Ministry to include data on all indicators eventually (MoT 2009).

4.1.2 Transport Agency *Statement of intent* result indicators

The Transport Agency publishes indicators in their annual SoI to demonstrate how the Transport Agency is progressing towards achieving the government's policy direction (NZ Transport Agency 2012a). Indicators are used throughout the SoI reporting against different areas of activity as shown in table 4.1. Some provide a measure of performance against a desired trend (eg increase or decrease), while others provide contextual information.

The indicators used can vary from year to year, and as they are aligned to government policy, can change as policy direction changes.

Table 4.1 Summary of indicators (from the SoI)

Area reported against	Indicator name/type and number
Desired long-term impacts of Transport Agency services, divided into eight areas.	Key result indicators and desired trend (8)
Value for money – divided into the three dimensions of: • financial management • delivery of core functions • investment that maximises return.	Value for money indicators, results and targets (10)
Priorities five – priorities that the Transport Agency chooses to focus on to progress towards the longer-term impacts.	Key result indicators and desired trend (6)
Organisational capability and health.	Key result indicators and desired trend/target (4)
Investment output classes (9 classes) - the performance of National Land Transport Fund (NLTF) investments.	Contextual result indicators and forecasts (34)

Source: NZ Transport Agency (2012a)

4.1.3 Review of New Zealand transport indicator frameworks

Denne et al (2013) were contracted by the Transport Agency to develop a best-practice indicator set for road transport in New Zealand. This included an extensive review of both the TMIF and Transport Agency indicator sets. Key critiques of the TMIF include its broad focus and lack of connection to wellbeing. Criticisms of the Transport Agency's indicator set include a lack of structure, a limited level of detail, and because they track performance against government policy objectives, some indicators are less useful for longer-term monitoring.

4.2 International indicator frameworks – gap analysis

A review of indicator frameworks used by other national and international organisations and government agencies was completed to help identify gaps in New Zealand's transportation indicator sets. The indicator sets included in this comparative review are listed in table 4.2.

Table 4.2 Indicator sets compared to New Zealand for the gap analysis

Indicator set	Jurisdiction
National performance indicators (Austroads 2013)	Australia
Annual performance monitoring bulletins (VicRoads 2012)	Victoria, Australia
Performance measures for road networks: a survey of Canadian use (Transportation Association of Canada 2006)	Canada
Model framework for the assessment of the state, performance and management of Canada's core public infrastructure (National Round Table on Sustainable Infrastructure & National Research Council 2009)	Canada
US national transportation statistics (Bureau of Transportation Statistics 2012)	USA
US highway statistics series (Office of Highway Policy Information 2011)	USA
National freight performance measures (Transportation Research Board 2011)	USA
ASEAN-Japan transport indicators (ASEAN–JAPAN Transport Partnership 2010)	ASEAN and Japan
Transport statistics Great Britain (Department of Transportation 2012)	Great Britain
European transport statistics databases (European Commission 2011)	Europe (European Commission)

A comprehensive table comparing New Zealand indicator frameworks with the datasets listed in table 4.2 is provided in appendix B. The appendix only includes road transport-specific indicators; indicators relating to other modes such as sea freight, rail and air flight movements were excluded. Some indicators listed in this table may be worded differently from their original indicator sets, in an effort to group indicators together where they measured the same things but used different units (eg miles versus kilometres) or subdivisions. For example, one indicator set may report vehicle kilometres travelled (VKT) for cars, trucks and motorcycles, and another might report for cars and trucks only. In this instance the indicator was recorded as 'VKT by vehicle type'.

The indicator frameworks surveyed varied in their coverage of transportation indicators. For example, only a few included mode share and travel perception indicators similar to the TMIF. This does not imply that such information is not collected. For example, the Department of Transport (2012) from Great Britain and Bureau of Transportation Statistics (2012) from the USA conduct similar travel surveys to New Zealand but report on these separately.

On first appearances, the TMIF is the most comprehensive and detailed dataset of all those surveyed; however, a number of the indicators from this dataset are currently not collected, as shown in table 4.3.

Table 4.3 TMIF2 indicators for which data is not currently collected

Indicator set	Indicator
Network reliability	Road network congestion (annual hours delay) Average reliability of journey times for key corridors Average journey times for key corridors
Freight and the transport industry:	Average load factor of heavy vehicles Percentage of heavy vehicle running empty
Access to the transport system	Access to essential services Percentage of the population who can get to key locations door-to-door by PT, walking and cycling Fully accessible buses and trains, as a percentage of the total fleet Percentage of fully accessible bus stops and train stations Number of wheelchair-accessible taxis Availability of accessible information about PT services
Transport safety and security	Resilience of the transport system Security of the transport system Total number of transport-related occupational health incidents
Public health effects of transport	Road traffic noise measurements
Infrastructure and environment	Length of foot path Cycle path quality Foot path quality Bus stop quality
Environmental impact of transportation	Total emissions of methane and nitrous oxide Energy use per tonne-km by domestic transport

A summary of key points arising from the comparison of New Zealand indicator datasets (the TMIF2 and the Transport Agency's SoI) against the other indicator frameworks examined is set out in table 4.4.

Table 4.4 Comparison of New Zealand and overseas transport indicator frameworks

Indicator set/category	New Zealand indicator frameworks	Comparison with overseas frameworks
Transport volume – includes indicators for distance travelled, fleet composition, occupancy and other modes – walking/cycling and passenger transport	New Zealand datasets are comparable to other countries in collecting transport volume information, particularly measures such as VKT and fleet composition.	Austroads (2013) reports against lane and car occupancy indicators on major urban arterial roads – this information is only collected from South Australia, Queensland, Victoria and New South Wales.
Network reliability – includes congestion, average travel times, reliability, delay, average speeds	Indicators of reliability and variability of travel times for Auckland, Tauranga, Wellington, Christchurch and Hamilton are reported in TMIF2. Indicators for congestion, average journey times and reliability for key corridors are also included in the TMIF, but there is no data for these. One delay measure reported in the SoI is a measure of network congestion in Auckland (minutes delay per km during AM peak)	A number of organisations use travel speed performance indicators such as average speeds. Austroads (2013) collects this information for major urban arterial roads only (in the states noted above). Delay measures are also collected by Austroads.
Freight and the transport industry – includes freight volumes and volume by distance for road freight; and economic indicators such as the contribution of transport and storage to GDP, and employment in the transport sector.	The TMIF2 includes a range of measures focused on volume and volume by distance for road freight. Most of the indicators in TMIF2 are similar to those used elsewhere, although TMIF2 is the most comprehensive.	The US National Freight Performance Measures (Transportation Research Board 2011) include a suite of freight demand and efficiency measures not reported elsewhere, including freight forecasts, urban and rural travel speeds and cost as a percentage of GDP.
Access to the transport system – access to motor vehicles and alternative modes, access to services, travel perceptions, public transit and mobility measures	The TMIF2 includes a comprehensive set of travel perception and accessibility indicators compared to other countries. However, some of these indicators do not have data available (see table 4.3).	Other indicator sets surveyed do not consider access or are very limited in scope compared to New Zealand. The Canadian Model Framework (Transportation Association of Canada, 2006) includes the broadest range of PT indicators, focused on the level of service provided by PT operations.
Travel patterns – mode share, methods of travel to work/school	The TMIF2 includes a large number of indicators for understanding travel patterns. The data behind most of these are reported from the New Zealand Household Travel Survey (MoT 2013b)	Only a small number of sources included indicators such as those used in the TMIF. Mode share journey to work is a common indicator in this regard. Both the US and Great Britain frameworks capture travel pattern information through National Travel Surveys, but do not report travel mode measures in their indicator frameworks (Bureau of Transportation Statistics 2012; DfT 2012)

Indicator set/category	New Zealand indicator frameworks	Comparison with overseas frameworks
Transport safety and security – accidents, deaths and injuries, contributing factors to accidents, social costs, security and resilience of transport networks	New Zealand's indicators for measuring the number or rate of crashes resulting in deaths and/or injury are comparable to the other indicator sets examined. The social cost of crashes and a selection of security measures relating to the transport system are also included in the TMIF2; however, indicators of resilience and security of the transport system have no definition and no data is collected for these.	Most indicators used elsewhere differ subtly in definition but represent similar information. Some key indicators not currently reported on in New Zealand include passenger casualty rates by mode (DfT 2012), and the number of lives saved by the use of restraints (Bureau of Transportation Statistics 2012).
Public health effects of transport – air and noise pollution	The TMIF2 includes nitrogen dioxide (N_2O) concentrations and Auckland light vehicle emissions as measures of the public health effects of transport. Although road traffic noise is listed as an indicator in TMIF2, no data is available for this.	Indicators of road traffic noise were only included in one indicator framework. Air pollutants (N_2O, VOC, PM, SO_x etc.) by vehicle type and/or transport modes are included in the US National Transportation Statistics (Bureau of Transportation Statistics 2012) and in the Canadian Model Framework (Transportation Association of Canada 2006).
Infrastructure and environment – quality and length of transport networks, expenditure and construction programmes	The TMIF2 indicators are largely limited to measures of infrastructure length and quality with no specific guidelines as to how quality is measured. Expenditure on infrastructure and services is also included in both the TMIF2 and SoI indicator sets. Measures of surface condition, smoothness of roads and pavement integrity in the SoI are much more specific measures of quality than the indicators used in the TMIF2.	A broad selection of infrastructure expenditure and construction indicators is included in most of the overseas indicator sets. The Canadian sources (Transportation Association of Canada 2006; National Round Table on Sustainable Infrastructure and National Research Council 2009) record the most comprehensive sets of specific road quality measures.
Environmental impact of transport – CO_2/greenhouse emissions, fuel and energy consumption	The TMIF2 includes indicators of carbon dioxide (CO_2) emissions and energy consumption measured per vehicle, per person and per tonne-km. The SoI also includes fuel consumption efficiency indicators. Methane and nitrous oxide emissions are included in the TMIF, but no data collected for these. Data is also no longer collected in the TMIF2 for energy use per tonne-km because there are no quality measures or estimates of bus passenger travel (MoT 2012).	The US and Great Britain indicator sets (FHA 2010; DfT 2012) include measures of fuel consumption and efficiency not reported in New Zealand. The number of vehicles scrapped is another relevant environmental indicator (Bureau of Transportation Statistics 2012).
Transport-related price indices –fuel prices, vehicle running costs, duties and road user taxes, PT fares and revenue.	The TMIF2 reports against consumer, construction and labour price indices for the transportation industry. Petrol pump, diesel pump, oil prices and road user charges (RUC) are also listed.	Many of the indicators used in New Zealand are included in the US and Great Britain indicator sets (Bureau of Transportation Statistics 2012; DfT 2012). Some additional indicators reported on include: petrol affordability index (VicRoads 2012) and road construction tender price index, freight revenue per tonne by distance and average user costs for PT and private vehicle travel (Bureau of Transportation Statistics 2012).

4.2.1 Key conclusions from gap analysis

From the gap analysis, the following are key conclusions regarding New Zealand's current land transport monitoring frameworks in comparison with frameworks from overseas:

- New Zealand's TMIF2 is the most comprehensive indicator set compared with those used elsewhere, but it lacks a clear focus and data for some key indicators is not collected or available. The size of the indicator set makes it difficult to get a clear overview of the state of the transport network and any developing trends.
- The Transport Agency's SoI indicators are linked to government policy direction and, while very specific, provide only a small part of the picture.
- There are some specific, unique indicators used elsewhere that could be relevant to New Zealand and worthy of further investigation.
- Each indicator set used by each organisation or country is designed to report on the conditions and objectives that are specific to that country or organisation, using the information that is available. No one dataset represents 'best practice' for New Zealand conditions.

4.3 Initial indicator framework development

Due to the limitations of the current land transport indicator dataset, there is a desire by the Transport Agency to move towards an indicator framework that is more in line with international best practice. Other organisations, such as Austroads (2013), are taking a similar approach.

4.3.1 A best practice indicator framework for land transport

Denne et al (2013) prepared a best practice indicator framework for land transport for the Transport Agency. As part of this, an extensive review of the existing New Zealand and international indicator frameworks and indicator best practice literature was undertaken and reported. The following seven factors were identified as being relevant for the development of a New Zealand land transport indicator framework:

1. Policy relevance – indicators must be relevant to actual policy 'levers' available to transport policymakers, but robust to changes in policy direction over time.
2. Wellbeing – indicators must have a clear connection to wellbeing.
3. Data availability and quality – the actual data that is available and its quality are practical considerations. Data needs to be statistically robust.
4. Comparability – indicators should be comparable across jurisdictions, across time and across sectors, where possible.
5. Simplicity and transparency – indicators should not be unnecessarily complex and the data and method of calculation should be transparent.
6. Cost effective – the cost of any data collection or manipulation to generate indicators should be balanced against their usefulness.

The second point on wellbeing supports the new indicator framework promoted by Denne et al (2013), which is centred on the concept of wellbeing as a measure of transport activity. It is argued that wellbeing is not a direct outcome of transport, but that transport promotes wellbeing by enabling and enhancing activities involving human interaction and trade. Conversely, transport can have a negative impact on wellbeing through externalities such as crashes and environmental and health impacts.

Using the wellbeing approach, the proposed indicator is categorised according to the characteristics of the transport system that are relevant to aggregate wellbeing:

- measures of the ability and performance of the transport system to move people and freight when and where required
- measures of the extent individuals suffer physical injury and property damage from transport services or activities
- indicators of the impact of transport activity on the natural environment and human health
- indicators of the financial cost to users of the transport system.

4.3.2 Initial indicator framework

The review of existing New Zealand transport indicator frameworks against overseas equivalents supports the findings of Denne et al (2013) report and also highlights some additional indicators that could be generated using emerging digital data sources. From this research, an initial indicator framework was established and endorsed by the Project Steering Group, identifying a range of indicators that could potentially be informed by digital data sources (table 4.5).

This framework developed iteratively through the course of the research project as new data or background information arose, or in response to suggestions from the Steering Group.

Table 4.5 Initial indicator framework

Indicator set	Indicator
Network performance and capability	Throughput (people moved)
	Average travel time/speed (private travel)
	Average travel time/speed (PT)
	Travel-time variability – delay
	Travel-time reliability – standard deviation and percentiles
	Travel-time reliability – peak
	Variation from speed limit
	Traffic volume
	PT on-time reliability
	Network condition: road
Health and environment	PM_{10}/N_2O emissions
	Carbon dioxide emissions
Safety	Number and rate of serious injuries and deaths
	Rate of total social cost of incidents
Activity	Total VKT
	Total tonne-km travelled
Cost	Cost per VKT
	Cost per freight tonne kilometre travelled

4.4 Interactive presentation of indicators

The literature review included an investigation into similar research to that undertaken for this research project. While there are no specific examples of projects that explore the potential of emerging technologies as a means of informing network performance indicators, there are examples of interactive, online indicator maps available overseas.

These include regional, national and international examples, and provide public information that allows users to compare road and traffic indicators across road networks and jurisdictions. In this regard they have some similarities to the proof-of-concept model developed as part of this research.

4.4.1 US national transportation facts and figures

The *US national transportation facts and figures* web mapping application, hosted by the Bureau of Transportation Statistics (2012) and also available at US Department of Transportation (2013a) provides state-by-state transportation facts, comparisons and rankings on the following topics:

- infrastructure
- fatalities and injuries
- distracted driving and safety equipment
- freight volumes and values
- passenger travel
- economy and finance
- energy and environment.

As well as the mapping interface, comparisons between states can be viewed in charts and downloaded directly from the website.

4.4.2 American Recovery and Reinvestment Act of 2009 projects

The American Recovery and Reinvestment Act of 2009 website (US Department of Transportation 2013b) maps projects that are overseen by the various administrations at the US Department of Transportation: the FHA, Federal Aviation Administration, Transit Administration, Railroad Administration and Office of the Secretary.

Funding information is mapped to allow comparison across state, county and congressional district levels. This information is updated on a weekly basis. Project information can be exported to PDF or an Excel spreadsheet.

4.4.3 European Union – Eurostat transport statistics

Eurostat, the statistical office of the European Union, publishes a transport statistical database combining tables, graphs and maps in a user interface (European Commission 2011). Information is displayed at provincial and national level, depending on the indicator chosen, enabling comparisons within and between countries. Eurostat includes a range of indicators for railway, road, inland waterways, maritime and air transport.

Road transport indicators include road accidents, volume of passenger and freight transport, length of motorways and motorisation rates. The user interface also supports the creation, download and printing of tables, graphs and maps.

4.4.4 TransGIS – Oregon Department of Transportation

TransGIS is a web mapping tool presenting information from the State of Oregon's transport management system (Oregon Department of Transportation 2013). The tool maps information regarding:

- assets (eg bridges, maintenance facilities, pavement conditions
- geo-environmental (eg soils, rainfall, wildlife collision hotspots)
- safety (eg crashes)
- traffic (eg annual average daily traffic (AADT), recorder stations, traffic flow, truck flow, posted speed, congestion)
- highway classifications
- rail network and infrastructure
- freight (eg high clearance routes, freight system highways)
- boundaries.

The analysis capabilities of the web map include being able to identify map features, measure distance and areas, and retrieve coordinate locations. Unlike the other examples provided, data cannot be downloaded in any format from this portal.

5 Conceptual framework

This chapter summarises the development of a conceptual framework to link the identified emerging digital data sources in New Zealand to the best practice transport monitoring indicators to measure the performance of the SH network.

Using sample data provided by a range of digital data suppliers, each indicator was tested to determine whether it was feasible to evaluate the indicator with the emerging data source. In doing so, the indicator set has been refined by removing, updating or adding new indicators. The final indicator set carried through to the proof-of-concept model is presented at the end of this chapter in table 5.2.

5.1 Sample data

Each digital data supplier identified in the New Zealand technology review was asked to provide sample data to help the project team identify what indicators could be interpreted from the data, and how well this data would interface with a GIS for the development of the proof-of-concept model.

Nine data samples were received, covering the four technology types: Bluetooth, GPS, mobile and WiM. A description of each data sample is summarised in table 5.1, identifying their size and attributes. The names of the suppliers have not been identified to protect the commercial interests of each organisation, and to adhere to the principles by which the Transport Agency commissions research.

Most suppliers were able to provide the data in a range of formats, time ranges, time intervals and varying degrees of spatial coverage as required by their clients.

Table 5.1 Attributes of datasets from GPS and Bluetooth suppliers

Attribute	A	B	C	D	E	F	G	H	I
Technology	BT	GPS	BT	GPS	GPS	GPS	GPS	Mobile	WiM
Ave speed/ time	Y	Y	Y	Y	Y	Y	Y	N	Y
Min/max speed/ time	N	Y	Y	N	Y	N	N	N	Y
Percentiles speed/ time	N	N	N	Y	Y	N	N	N	Y
Standard deviation speed/	Y	N	N	Y	N	N	N	N	Y
Vehicle counts or device matches	Y	Y	Y	Y	Y	N	N	Y	Y
Time interval	15 or 30 minutes	Every vehicle	15 minutes	60 minutes	15 minutes	Every vehicle	15 or 60 minutes	15 minutes	Every vehicle
Number of point locations or road segments[1]	38	5,942	42	100	31	3	117,280	24	1
Days of data	5	1	20	1	1	2 (am only)	7	7	62
Vehicle class	N	N	N	Y	N	N	N	N	Y

[1] Includes both directions (eg one corridor with both ‘to’ and ‘from’ data is equivalent to two road segments).

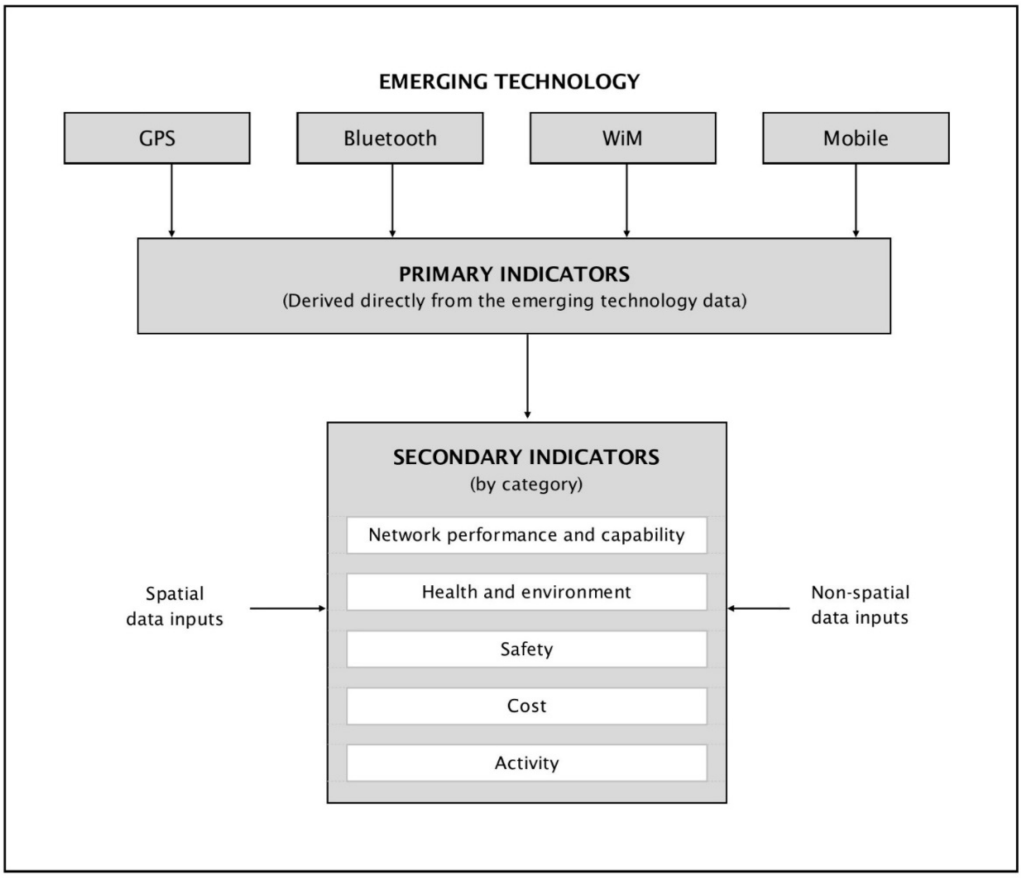
Attribute	A	B	C	D	E	F	G	H	I
Mode/fleet	All	PT	All	Comme rcial	Com-mercial/ private	Com-mercial/ private	PT	All	Heavy
Time data format	CSV	CSV	CSV	ESRI shape-file	CSV	Excel	CSV	CSV	CSV
Spatial reference	KML	Start/ end co-ordinates	Inter-preted from map		Start/ end co-ordinates	Way-point descript-ion	ESRI shape-file	Inter-preted from map	Co-ordinates

5.2 Indicator framework development

Using the indicator framework set out in table 4.5, each sample dataset was tested to determine the feasibility of using the data to generate the indicators. This step also included a sensibility check as to whether the emerging digital data added value to what was currently available (for example, by providing a higher resolution or improved quality of data) and to ensure that the outcomes were meaningful, useful, and met the objectives of the research. Where available and appropriate, current Transport Agency procedures were referenced to provide consistency between the derived indicator framework proposed in this research and other Transport Agency procedures, guidelines and subsequent reporting.

The final output of the indicator framework development was a final indicator set that was carried forward into the proof-of-concept model. Figure 5.1 is a high-level diagram of the framework presented in this chapter.

Figure 5.1 Model conceptual framework



Using the emerging technologies, a suite of primary indicators were identified:

- speed (minimum, maximum, average, median)
- travel time (minimum, maximum, average, median)
- sample or vehicle count
- statistical measures of speed or travel time (standard deviation, percentiles).

These indicators reflect the outputs received from the data suppliers with little or no post-processing. Some of these indicators can be separated out by transport mode and/or vehicle type.

Secondary indicators are derived from the primary indicators by undertaking additional post-processing and may require additional information inputs such as expansion factors, cost inputs and inputs from other research. Some of the additional data requirements are spatial attributes (eg gradient and corridor length).

5.2.1 Network performance and capability indicators

5.2.1.1 Throughput (people moved)

Throughput is defined as 'the weighted average number of people moved on a representative sample of key routes during the peak hour' and is measured as 'a product of vehicle flow and average load factor' (Denne et al 2013). The challenge is that instead of counting vehicles as is traditionally measured, this indicator counts people regardless of whether they are private or PT users, and could be expanded to include cyclist and pedestrian movements as well.

Mobile technology can record the number of road network users across all transport modes, including pedestrians and cyclists, in addition to motorised travel. It is plausible that mobile technology could be used to estimate the number of people moving along a pre-defined route. The careful calculation of expansion factors would be required to factor up any mobile network dataset results to be representative of the full population.

The sample mobile dataset evaluated by the research team recorded the number of phone calls, text messages and data usage by a number of mobile phone towers in Auckland; however, the data did not triangulate the actual position of each mobile phone user, nor did it track the movement of users between mobile phone towers. Therefore, it was not possible to generate speed or travel-time data associated with the underlying transportation networks.

The feasibility of using mobile phone data to estimate traffic flows was also tested by profiling mobile phone use by time of day. The analysis compared the profile of traffic flows from traffic count stations in the direct vicinity of a tower with the recorded mobile usage data. The analysis (which has not been presented in detail in this report due to the confidentiality agreement between the authors and the vendor) clearly showed that mobile phone use reflects business hour activity with respect to call activity, and a mix of business and recreational activity with respect to text messaging and data usage. There was no relationship between phone use and travel demand as the data includes both travellers and non-travellers. Following consultation with mobile data suppliers, it is understood that there are also a number of privacy issues around the provision of this data which limit the extent to which data can be made readily available.

Due to technology and data constraints, it was concluded that mobile phone data cannot currently be used for generating any road performance indicators. The use of mobile phone data as a source of data for throughput (or other road performance) measures should not be excluded entirely as the development of mobile opt-in applications may prove to be a promising data source in the future.

5.2.1.2 Average travel time and speed (all modes)

Average travel time or average speed are primary indicators that can be generated directly from all the digital data sources. While travel time (and travel-time variance) provide a measure of performance for a single road segment, the relative measure of speed enables the comparison of performance between similar road corridors.

The emerging technologies available in New Zealand provide scope to replace conventional methods such as floating car surveys for measuring travel time. No additional data inputs are required to facilitate the calculation of travel times; however, centreline distance is necessary to convert travel time to speed (and vice versa), if not already provided by the data supplier.

For calculating average travel times on PT journeys, data collected from GPS technology on buses recording stop departure and arrival times is also available. Acknowledging that most PT travel occurs on local roads and less travel occurs on the SH network, there may be limited applicability for the calculation of PT travel times within the context of this study. Another limitation is that only the in-transit travel time is collected. Transfer times between services, and access and egress travel time (whether by walking or private vehicle) at each end of the journey is not taken into account.

5.2.1.3 Minutes of delay

Minutes of delay per km is an indicator that reflects the level of congestion along a particular link at a particular time. This indicator can be derived by comparing the recorded average travel time with an expected free-flow travel time.

Because this indicator is independent of corridor length and speed limit, it is the only measure that will allow comparisons of performance or congestion across the road network, regardless of hierarchy or speed environment. Provided a practical measure of free-flow travel time can be defined, this indicator can easily be calculated from the sample data provided.

5.2.1.4 Standard deviation and percentiles

Travel-time reliability reflects a measure of variance, capturing the expected range of deviation around the average travel time. Because all travel-time sample data received is aggregated to a standard interval (15, 30 or 60 minutes) by the data supplier, the calculation of standard deviation and percentiles (15th and 85th, or 5th and 95th) must also be calculated by the supplier. Not all data suppliers currently provide standard deviation or percentiles in their sample data, but this does not necessarily reflect their capacity to provide this in the future. At least one of the datasets that has standard deviation and/or percentile values has been included in the development of the proof-of-concept model.

A sufficiently large dataset is also required to extract standard deviation and percentile data, therefore it may be difficult to generate these indicators over short time periods or during periods of low traffic volume where there are few vehicles recorded.

5.2.1.5 Peak travel times (minimum/maximum)

Minimum and maximum travel times can be collected from GPS and Bluetooth data using the same methods as for average travel time (section 5.2.1.2). This data can be further broken down by time of day to represent both peak and off-peak travel-time reliability.

From the sample dataset, it was found that minimum and maximum travel times were more likely to represent 'outlier' values. For example, very slow travel times were detected on a number of Bluetooth routes in the middle of the night, possibly due to road maintenance or service vehicles. By contrast, some of the fastest travel times recorded exceeded the speed limit and therefore did not represent a typical traversal time. Because of these limitations, peak travel times (minimum and maximum) did not provide reliable measures of road network performance and were not carried forward into the proof-of-concept model.

5.2.1.6 Variation from posted speed

Variation from posted speed limit represents the difference between actual travel speeds and the posted speed limit. To calculate this indicator, the posted speed limits must be available from a reliable source and reviewed on a regular basis to take into consideration any changes implemented by road controlling authorities.

Variation from posted speed limit is a less reliable measure of congestion than minutes delay per km (see section 5.2.1.3), as on mountainous terrain it is expected that the safe free-flow speed would fall well below the posted speed limit and therefore not provide comparable outputs across a diverse road network. This measure could, however, be used to support a review of speed limits or to target areas for speed-related enforcement.

5.2.1.7 Traffic flow (VKT)

Currently, the total number of VKT per annum is calculated from warrant of fitness (WoF) and certificate of fitness (CoF) odometer readings (Denne et al 2013). While this is an effective way of estimating VKT across the country and by region, it cannot show where the VKT were recorded.

It is proposed that the GPS and Bluetooth sources be used to calculate estimates of VKT on the SH network. By recording the number of GPS records and Bluetooth signals or matches recorded at a specific location and carefully calibrating expansion factors in consideration of the level of sampling, traffic volumes for each road segment can be estimated. The traffic volume can then be used to calculate the total VKT on each road segment of the SH network by multiplying the traffic volume by the length of each segment, and this in turn can inform a range of other indicators. In addition, the distribution of Bluetooth or GPS counts over a 24-hour period can be analysed to provide a measure of estimated hourly flow.

The Bluetooth sampling rates have been quoted by the various providers as being in the order of 15% to 18% of the full traffic volume, but are likely to fluctuate somewhat depending on the demographics of the road users on each road corridor. It is clear that the sampling rates must be re-calculated on a regular basis for all data sources as expansion rates may change over time as the technology penetration increases (or decreases).

5.2.1.8 Public transport on-time reliability

The reliability of PT services is defined as the proportion of services operating within a defined margin of their scheduled time and can be measured for road, rail and ferry services alike. For a New Zealand indicator set, Denne et al (2013) recommend using five minutes as the defined margin for this indicator and measuring arrival reliability (eg when the service arrives at a way point) rather than departure reliability.

On-time reliability can be interpreted using the GPS data collected by PT operators and this is confirmed through interrogation of the sample data sets supplied from Auckland and Wellington. In addition to spatially locating the way points, service routes, bus stops, rail and ferry termini and scheduling information would also be required inputs.

As all ferry and rail services and the majority of bus services are not routed on the SH network, this indicator has limited applicability. In addition, the indicator provides a measure of service quality rather than network performance and is already monitored by regional councils as part of their contracts with bus operators and/or as performance measures in their long-term plans. For these reasons, it was agreed with the Project Steering Group that it would be inappropriate to carry PT on-time reliability forward to the proof-of-concept model.

5.2.1.9 Road network condition

The percentage of travel taking place on roads classified as being smooth is an asset management indicator that provides a measure of the quality of the road asset related to its use. This indicator has an excellent fit with the objectives set out in NZ Transport Agency (2012a), wherein the Transport Agency forecasts that over 97% of travel will occur on roads that are classified as smooth. According to Austroads (2007), an International Roughness Index (IRI) of 4.2 or less indicates acceptable travel conditions. Therefore it is proposed that this criterion be adopted to categorise those road segments considered as providing smooth travelling conditions.

The primary indicator, which enables this to be calculated, is the traffic volume recorded for each road segment. By aggregating the volumes and multiplying by the distance travelled along each road segment (with acceptable and unacceptable IRI), total VKT can be estimated as well as the percentage of travel on roads classified as smooth. In the absence of network-wide measures of the IRI, any other acceptable measures of road condition could be used as a proxy attribute.

5.2.2 Health and environment indicators

5.2.2.1 Emissions ($PM_{10}/PM_{2.5}/N_2O$)

Emissions produced by vehicles along a road corridor are currently measured at key monitoring sites (Denne et al 2013); however, it is also possible to model the quantity of emissions produced by road transport using the procedure outlined in the *Economic evaluation manual* (EEM) (NZ Transport Agency 2013b). The specific emissions for which rates are available are carbon monoxide (CO), nitrogen oxides (N_2O), particulates (PM_{10}) and volatile organic compounds (VOC).

The primary indicators required for these calculations are the traffic volumes generated from sample counts and speeds on each SH road segment, which can both be evaluated from GPS or Bluetooth digital data sources. As volumes and speeds change throughout the day, estimated hourly volumes and hourly average speeds can also be mapped and aggregated into hourly and/or daily totals.

5.2.2.2 Carbon dioxide emissions

A calculation for total CO_2 emissions can be found within the EEM. This calculation is based on MoT's vehicle emissions modelling which is understood to stem from analysis undertaken in 1998, but has since been updated and refined. CO_2 emissions are calculated as a function of vehicle operating costs for road links and fuel consumption for intersections where a transport modelling tool is available to support this evaluation.

MoT staff confirmed there is no formal report available supporting the evaluation referred to within the EEM, so a simplified evaluation is proposed where CO_2 costs are estimated as 4% of total vehicle operating costs as specified in section A9.7 of the EEM. By back-calculating at the specified rate of $40/tonne, a measure of the concentration of CO_2 emissions for each road segment and time of day can be determined.

To calculate vehicle operating costs, a number of additional data inputs are required, including road-related variables (gradient, hierarchy and urban/rural split) and calculation tables from the EEM. While a specific road gradient dataset is not currently available this can be calculated using GIS by comparing the relative heights at each end of a road segment.

5.2.3 Safety indicators

5.2.3.1 Number and rate of serious injuries and deaths

The number of deaths and serious injuries nationally are currently calculated from crash statistics in the Transport Agency's Crash Analysis System (CAS) as documented in NZ Transport Agency (2012b). Rates of deaths and serious injuries are then calculated using VKT.

As an alternative to using VKT for rates of deaths and serious injuries, Denne et al (2013) suggest the use of a rate based on total person km travelled for both private and PT modes, in order to better reflect the risk faced per user or per usage basis. Some of this information can be sourced from the New Zealand Household Travel Survey which records travel mode preferences and distances travelled on a regional basis (MoT 2013b). Emerging technology can provide a measure of VKT for a particular road section of the SH network, which can either be used to calculate rates from CAS data or as part of a predictive model, measuring the predicted rate of serious injuries and deaths by location.

An existing Transport Agency tool is SafetyNET, an online road safety tool that displays crash data (for the previous five years) and a number of other attributes for each section of the SH with a speed limit of 80km/h or higher (Durdin and Jansen 2012). The number and rates of fatal and serious injury crashes are calculated for 100m segments of the SH; however, these short lengths of road are combined into 500km or 5km road corridors for reporting purposes.

Because SafetyNET and the underlying Transport Agency RAMM data that supports SafetyNET already provide a comprehensive methodology for assessing and reporting road safety risk, it was agreed by the project team and the Project Steering Group that additional measures of the number and rate of serious injuries and deaths, derived from the digital datasets, did not add value to the existing tools available. Instead, an alternative measure of 'VKT by road assessment rating' is proposed in section 5.2.3.3.

5.2.3.2 Rate of total social cost of incidents

The social costs of incidents are published in MoT (2012c) and can be multiplied by the CAS data, supplemented by the VKT information from the emerging technology primary indicators, to calculate the actual rate of social costs. Alternatively, the social cost associated with the predicted rate of incidents can be calculated by multiplying the MoT social costs by the predicted number and severity of incidents based on the SafetyNET methodology as proposed in section 5.2.3.1.

Although this indicator could feasibly be generated from the digital data sources, for the same reasons as expressed in section 5.2.3.1, it was decided that this did not add value to the existing tools and methodologies available to the Transport Agency. In any event this can be derived as a function of the number and rate of death and serious crash injuries using Transport Agency cost guidelines from the EEM (NZ Transport Agency 2013b).

5.2.3.3 Vehicle kilometres travelled by road assessment rating

The New Zealand Road Assessment Programme (KiwiRAP) provides a star rating of the SH network infrastructure. Star ratings are an objective measure of the level of safety built into roads (KiwiRAP 2010a) based on physical characteristics and traffic volumes. The star rating of the entire high-speed SH network (80km/h and above) is mapped to demonstrate those sections that have a poor level of built-in safety (one star) and those sections with an excellent level of built-in safety (five star) (KiwiRAP 2010b). KiwiRAP star ratings are derived from a calculation that combines a visual assessment of the numerous physical characteristics with the traffic volume for every 100m length of road known as the road protection score (RPS).

This new measure was developed following discussions and investigations into the feasibility of indicators measuring the number and rate of serious injuries and deaths. The existing KiwiRAP and SafetyNET tools provide crash statistics for the SH, including star ratings that classify roads by the level of risk to motorists. Star ratings per VKT are calculated at a regional level using WoF/CoF data; however, this data is not available at a road corridor level, nor is it estimated for each corridor based on AADT traffic volumes from Transport Agency RAMM data.

The RPS indicator can potentially be informed through emerging digital data sources by calculating VKT from available Bluetooth or GPS data sources (see section 5.2.4.1) and then aggregating the resultant total VKT by KiwiRAP star rating. Using VKT data interpolated from GPS or Bluetooth match rates and the average (weighted) star rating for the road corridors monitored, a measure of VKT by road assessment rating can be displayed. The updated VKT data can also be converted to traffic volumes to ensure the RPS and star ratings are routinely updated as traffic volumes change.

5.2.4 Activity indicators

5.2.4.1 Total vehicle km travelled

VKT per annum is currently calculated from WoF/CoF odometer readings (MoT 2012a); however, this only records VKT at a national or regional level, classified by where the WoF or CoF was issued, rather than attributing VKT to a particular locality or specific road corridor. Additionally, the New Zealand Household Travel Survey (MoT 2013b) can be used to estimate VKT based on the data collected through participants' travel diaries.

As discussed in section 5.2.1.7, emerging technology can be used to calculate estimates of traffic volumes and VKT on the SH network, by expanding sample count data to estimate corresponding traffic volumes. The resultant estimate can be validated by checking the data against RAMM data which calculates VKT based on volumes from specific SH road segments. By multiplying the length of each road segment by the expanded traffic volume the total VKT on the monitored SH network can be estimated and readily updated as more traffic data is collected.

Additional value can be delivered by estimating the total VKT by road hierarchy and by calculating VKT using an urban and rural split. Any other GIS layers which are available on the SH road network centreline can similarly be used to further disaggregate the total VKT indicator.

5.2.4.2 Total tonne-km travelled

The total number of VKT per annum for heavy goods vehicles (HGV) can be estimated based on WoF/CoF odometer readings (MoT 2012a) but it is not possible to locate where the VKT have occurred on the SH network.

WiM isolates HGV volumes but only at six locations across the country. Due to the lack of coverage and the inability to highlight variability in traffic volumes across the SH network, WiM is not considered to be a useful input data source for this indicator unless coverage significantly improves in the future.

A methodology to expand GPS heavy vehicle counts could be applied to compare the GPS heavy vehicle counts with known percentage heavy vehicle data from Transport Agency count sites. If data specific to the heavy commercial vehicle fleet can be isolated, heavy vehicle VKT could be calculated using the methodology discussed in section 5.2.4.1 above, and an average weight loading applied to generate total freight load values.

5.2.5 Cost indicators

5.2.5.1 Cost per vehicle kilometre travelled

Denne et al (2013) propose a measure of cost per person km travelled, which represents the fixed and variable costs of personal transport, incorporating both public and private transport modes. The cost of travel for vehicle passenger, PT and active transport modes cannot be calculated from emerging technology data sources as travel times and distances for each mode cannot be isolated.

In the EEM, the calculation of travel costs is defined separately for vehicle operating costs (eg fuel costs, tyres, repairs and maintenance, oil and depreciation) and travel-time costs (in relation to the cost of time spent travelling). To calculate vehicle operating costs an average speed is required, as well as additional data inputs for grade and road environment (hierarchy and urban/rural classification). For travel-time costs, the total number of hours travelled is required, as well as the road environment classification.

Emerging data sources (GPS and Bluetooth) capture average speed data, while the total number of hours travelled can be interpreted from vehicle counts (AADT or estimated hourly volumes) and travel-time data. As such, it is possible to estimate total and rates of cost from the data provided.

Other additional vehicle operating cost components due to congestion, bottleneck delay and speed change cycles are more difficult to incorporate as the data available relates to road segments rather than speed and delay experienced by individual vehicles. Further costs to road users such as parking costs are likewise not considered.

In addition to calculating the rate of cost per VKT, it is proposed that total cost also be calculated by expanding the cost rate by VKT.

5.2.5.2 Cost per freight tonne-km travelled

The total fixed and variable costs of freight transport per freight tonne (or per freight tonne-km) provide an overarching cost indicator for freight transport across all modes. This indicator focuses on the total freight costs of the transport system and can be supported by existing Transport Agency financial modelling of freight activities (Denne et al 2013).

One GPS sample dataset was received in spreadsheet format, containing speed data (including minimum, maximum, average, percentiles and standard deviation) by road user class for defined road segments. Vehicle sample counts were also provided (by road user class) and could be used to determine AADT and/or estimated hourly volumes.

In addition to calculating the rate of cost per VKT, it is proposed that total freight cost also be calculated by expanding the freight cost rate by freight VKT.

5.3 Summary of indicators

The indicators identified as being able to be calculated from the emerging technology digital data sources are summarised in table 5.2. Each of the indicators has been assigned a code for ease of reference, the prefix of which indicates the category to which they belong.

Table 5.2 Final indicator set

Code	Indicator	Primary indicator	Other data requirements
Network performance (NP) – travel time and speed			
NP1.1	Average travel time – private vehicle	Average travel time	n/a
NP1.2	Average speed – private vehicle	Average speed	n/a
NP1.3	Average travel time – PT	Average travel time	n/a
NP1.4	Average speed – PT	Average speed	n/a
Network performance (NP) – travel-time reliability and variability			
NP2.1	Minutes delay per km – private vehicle	Average travel time	Free-flow travel time Road segment length
NP2.2	Minutes delay per km – PT	Average travel time	Free-flow travel time Road segment length
NP3.1	Standard deviation speed	Standard deviation speed	n/a
NP3.2	15th percentile speed	15th percentile speed	n/a
NP3.3	85th percentile speed	85th percentile speed	n/a
NP4	Variation from speed limit	Average speed	Speed limit
Network performance (NP) - volume			
NP5	Estimated hourly volume	Sample count	Expansion factors Known AADT
Health and environment (HE)			
HE1.1	Rate of emissions – CO	Average speed Sample count	EEM A9.3 procedure Expansion factors
HE1.2	Rate of emissions – N_2O		
HE1.3	Rate of emissions – PM_{10}		
HE1.4	Rate of emissions – VOC		
HE2	CO_2 emissions (total)	Average speed Sample count	Road gradient Urban/rural classification Road hierarchy classification EEM A5.7 Costs EEM A9.7 Procedure Expansion factor(s)
Safety (S)			
S1	VKT by star rating	Sample count	Star ratings Expansion factors
Activity (A)			
A1	VKT	Sample count Average travel time	Road segment length
A2	Total freight tonne kilometres	HCV sample count Average travel time	Average freight load value
Cost (C)			
C1.1	Cost per VKT	Average speed Sample count	Expansion factor(s) Road segment length
C1.2	Total cost of travel		
C2.1	Cost per freight tonne kilometre	Average HCV speed HCV sample count	Average HCV freight load Road segment length
C2.2	Total cost of freight travel		

The investigation of emerging technology sample datasets resulted in the development of a set of 23 primary and secondary indicators, which can be generated from emerging technology sources and are candidates for inclusion in the development of a proof-of-concept model.

All 23 indicators identified are derived from GPS or Bluetooth sources. It was found that no specific network-wide indicators could be developed using the application of WiM technology due to the very limited coverage provided by the technology. It was not possible to establish a relationship between the mobile technology dataset received and any underlying traffic indicators.

6 Methodology development

This chapter explores the methodologies for generating the 23 indicators identified by the research from the sample digital data provided by Bluetooth and GPS data suppliers.

The following sections discuss each of the indicators in turn and test alternative methodologies (where possible) to determine how they could be derived from one or more sample datasets. Extensive interrogation of the sample datasets was undertaken to understand the key limitations and feasibility of producing the indicators from each dataset.

The dialogue in each section extends to include recommendations as to the appropriate application of the data to inform the proof-of-concept model, and outlines any assumptions, limitations and other considerations that might influence the development of the model.

6.1 Indicator calculations

6.1.1 Average travel time and speed (private travel) (NP1.1 and NP1.2)

The sample data provided can be used to reliably calculate average travel times and speeds for 15-minute intervals.

Figure 6.1 corresponds to 11 contiguous sections of the Auckland motorway in each direction, producing 22 separate datasets for a 24-hour period. All sections have a 100km/h posted speed limit. Marginal sample sizes at various times of day can result in somewhat lumpy reporting, as shown between 9pm and 5am in this figure. Despite this corridor having among the highest traffic volumes of all recorded sites on the SH network, the 1.6% sampling rate and the fact that the data only represents a single day of vehicular demand, resulted in inconsistencies in the speed profiles.

Figure 6.1 SH1 examples of speed in 15-minute increments on 22 road segments

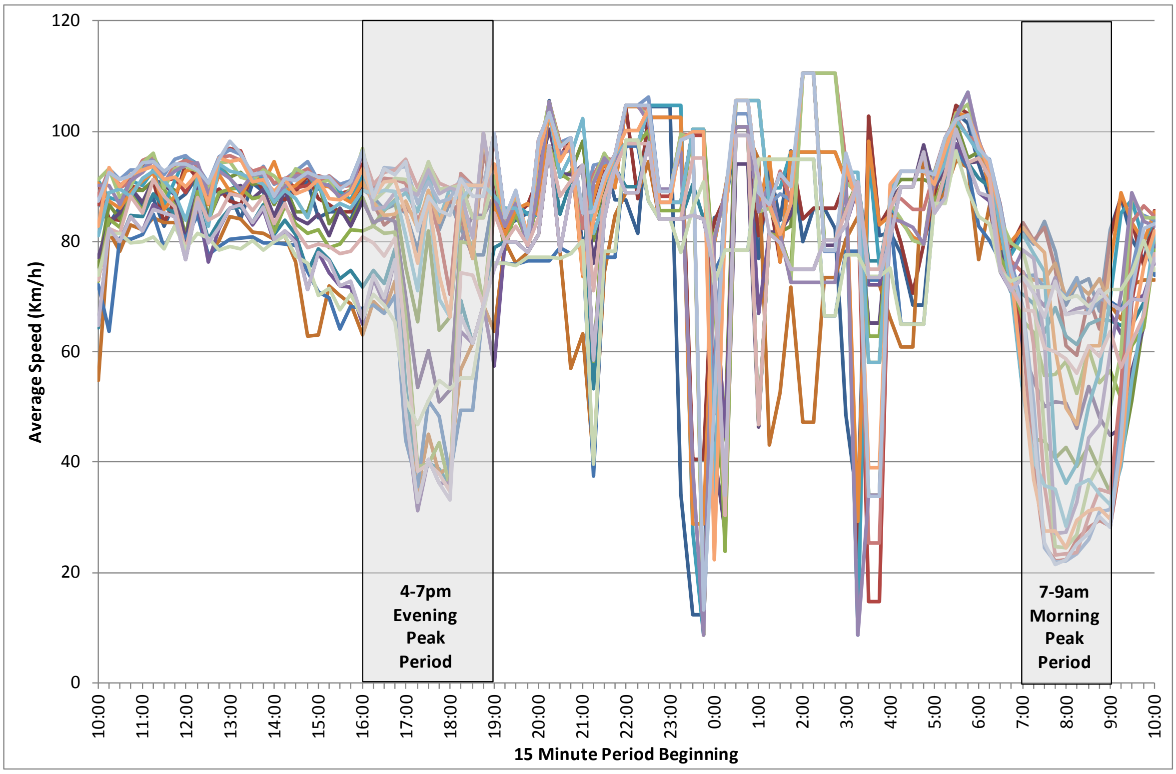


Figure 6.1 shows that:

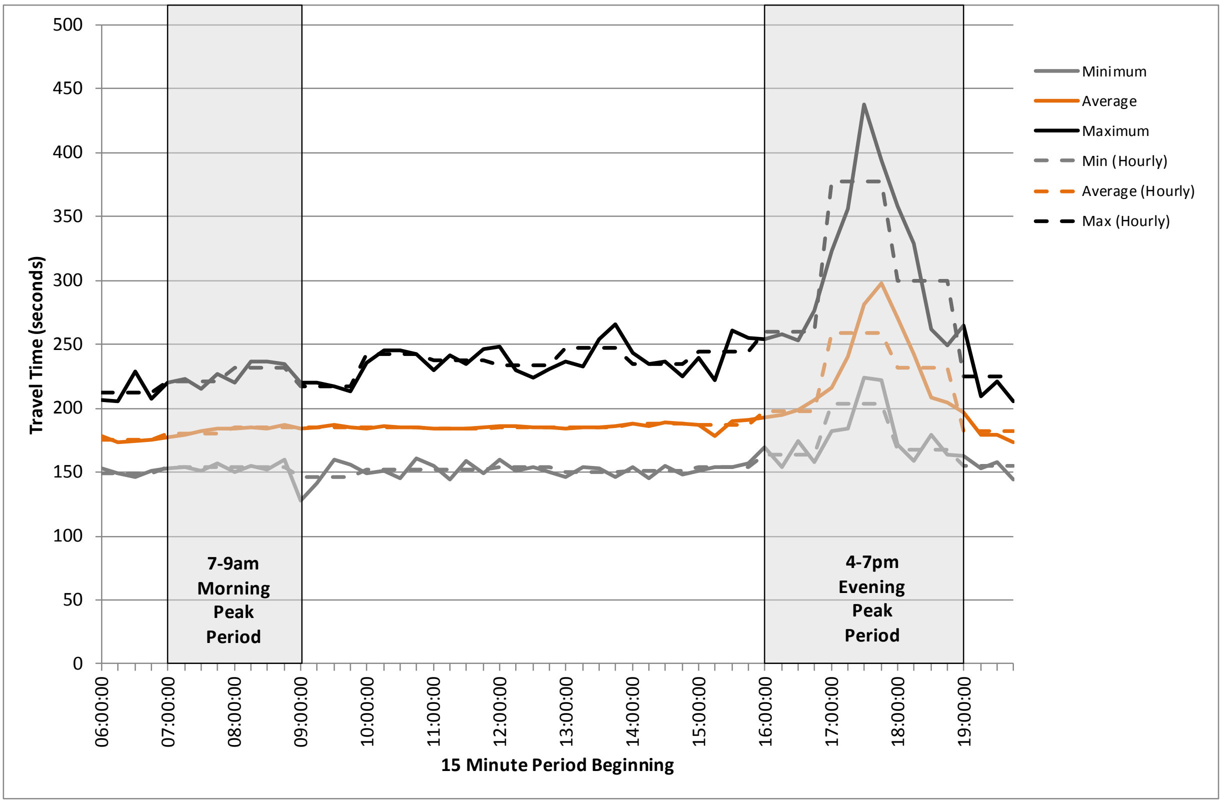
- during morning (7am to 9am) and evening (4pm to 7pm) peak periods, the impact of congestion is evident and speeds can vary considerably from one 15-minute period to the next
- between 10am and 3pm, speeds are relatively uniform across the road segments
- between 8pm and 5am when traffic volumes are comparatively low, the sample data returns values based on a very small number of vehicles with some of the lowest speeds recorded, possibly corresponding to road maintenance, cleaning or service vehicles.

In order to produce meaningful travel-time and speed indicators it is recommended that data be aggregated to both time-of-day periods and across a week or month to provide a more robust measure.

Another set of sample data was analysed by aggregating a month of weekday travel times and extracting the minimum, average and maximum daily travel times in 15-minute increments as shown in figure 6.2. This figure represents a 4.3km road segment of Auckland motorway in the northbound direction, where tidal flow would be expected during the evening peak period. By aggregating monthly data, the average travel time outside the peak period does not fluctuate (when compared with figure 6.1) and daily minimum and maximum travel times remain relatively consistent.

The 15-minute minimum, average and maximum travel times shown as solid lines in figure 6.2 have been aggregated into 60-minute typical values as dotted lines. By taking the average of the four 15-minute data points for each hour, a smoothed representation of the fluctuations in minimum, average and maximum travel times experienced on the network is evident.

Figure 6.2 Example of daily travel-time profile from aggregated data



The evening peak period clearly straddles three hours with changes in travel times identified between the 15-minute time periods within the peak period. This trend is mirrored by the corresponding minimum and maximum travel-time results. A single peak period value (whether it represents two hours or three hours) is likely to moderate the reporting of the impact of congestion; however, reporting hourly averages may be a practical alternative to remove the lumpiness in the output reporting.

For the purposes of developing the proof-of-concept model, the data should be aggregated to a typical weekday period, and reported against at hourly intervals. This level of aggregation is also recommended for all secondary indicators derived from travel time or speed, as discussed in the following sections.

6.1.2 Average speed and travel time (PT) (NP1.3 and NP1.4)

The Auckland PT GPS data has been aggregated to report on travel times between adjacent bus stops, filtered by time of day. Unlike the other data provided, the PT sample data reports the actual arrival and departure times at stops for each bus on each route in the network, rather than providing travel time between defined monitoring points. An example subset of the type of data collected is shown in table 6.1.

Table 6.1 Auckland PT GPS data sample extract

Route #	Route Uid	Route name	Service start time	Stop sequence number	Stop #	Timetable arrival time	Sighting time entry	Sighting time exit
839	8391	LONG BAY TO MIDTOWN	13:47	100	3076	13:47	13:47:14	13:47:29
839	8391	LONG BAY TO MIDTOWN	13:47	200	3001	13:47	13:47:53	13:48:00
839	8391	LONG BAY TO MIDTOWN	13:47	300	3003	13:47	13:48:29	13:48:35
839	8391	LONG BAY TO MIDTOWN	13:47	400	3005	13:48	13:48:54	13:48:57
839	8391	LONG BAY TO MIDTOWN	13:47	500	3006	13:49	13:49:39	13:49:44
839	8392	MIDTOWN TO LONG BAY	15:05	100	7038	15:05	15:03:04	15:05:17
839	8392	MIDTOWN TO LONG BAY	15:05	200	7086	15:06	15:07:49	15:07:50
839	8392	MIDTOWN TO LONG BAY	15:05	300	7081	15:07	15:11:52	15:11:59
839	8392	MIDTOWN TO LONG BAY	15:05	400	7079	15:08	15:15:15	15:15:20
839	8392	MIDTOWN TO LONG BAY	15:05	500	7075	15:08	15:17:04	15:17:20

Table 6.1 displays data on two services along one route (route '839'). Each service has a unique identifier (Uid), with one service travelling in the outbound direction (route_uid = 8391) and the other inbound (route_uid = 8392). For each service, the start time is provided and stops are listed in sequential order (100, 200, 300 etc). Stop entry and exit times are provided from which travel time between sequential stops can be calculated.

The stop numbers provided in the sample data relate to actual bus stop locations with latitude and longitude coordinates. Up-to-date stop locations could also be extracted from a general transit feed specification data feed service, where available.

To generate travel time, road centreline links that join 'adjacent' stops on a route must be created using a GIS workflow as follows:

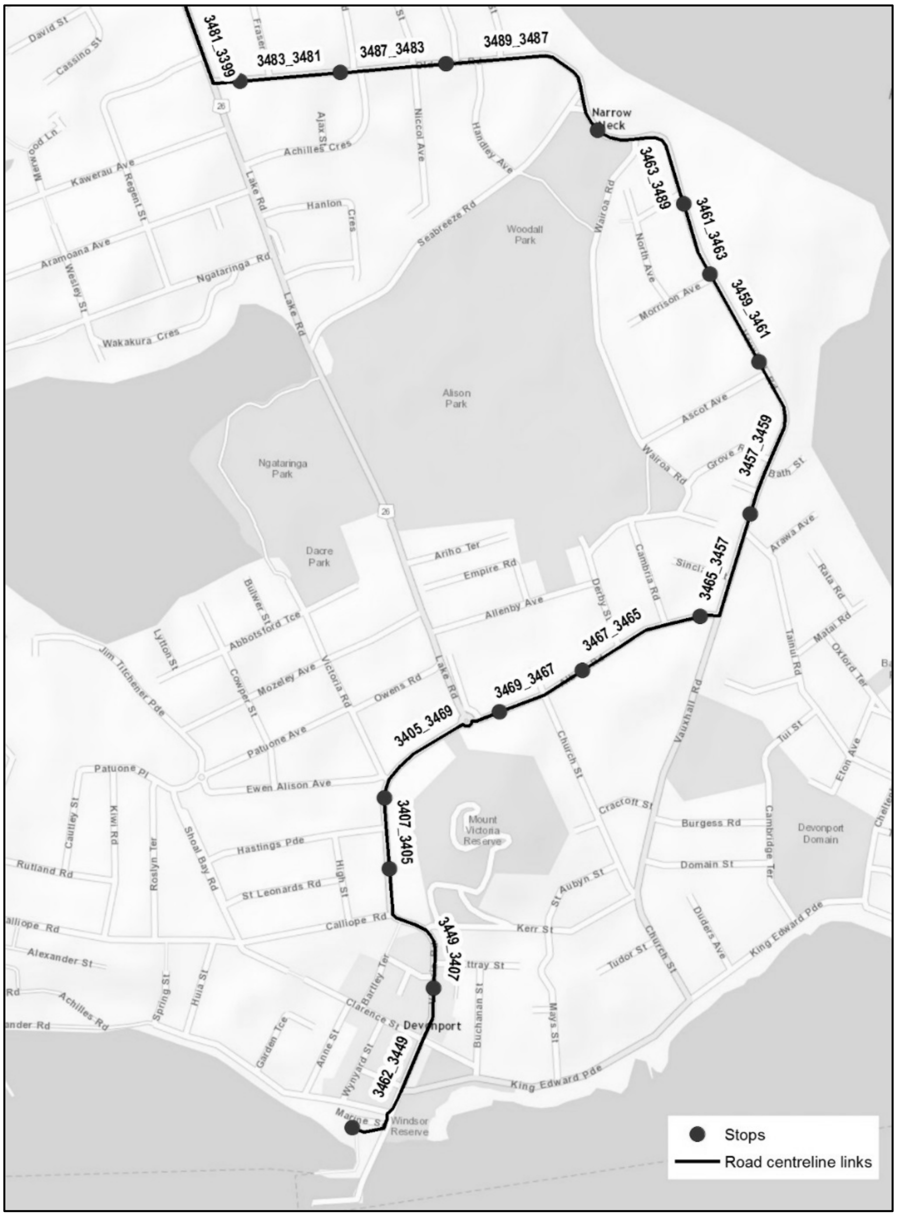
1. Map the bus stops using latitude and longitude coordinates and snap them to the closest road centreline.
2. Extract unique routes and services and the associated stop numbers and stop sequence.
3. For each unique route and service, undertake a 'shortest path' network analysis to generate a route between each stop, using the sequential order provided.

4 For each pair of stops), subtract *sighting time exit* from *sighting time entry* to generate *traversal time*.

5 Combine the outputs from (4) for every route and service by hourly period to generate average traversal times between stops.

The output of this analysis is a number of road centreline links that can be used to extract data on exit, arrival and traversal time across identified road segments. This format allows comparisons across all routes that use the same corridor. An example of a route that has been defined using this method is shown in figure 6.3. In this example, the road centreline segments have been labelled according to their unique ID, which represents the start and end stops for that segment.

Figure 6.3 Example of road centreline links for route 813 (Devonport to Takapuna)



6.1.3 Minutes of delay per km (private travel) (NP2.1)

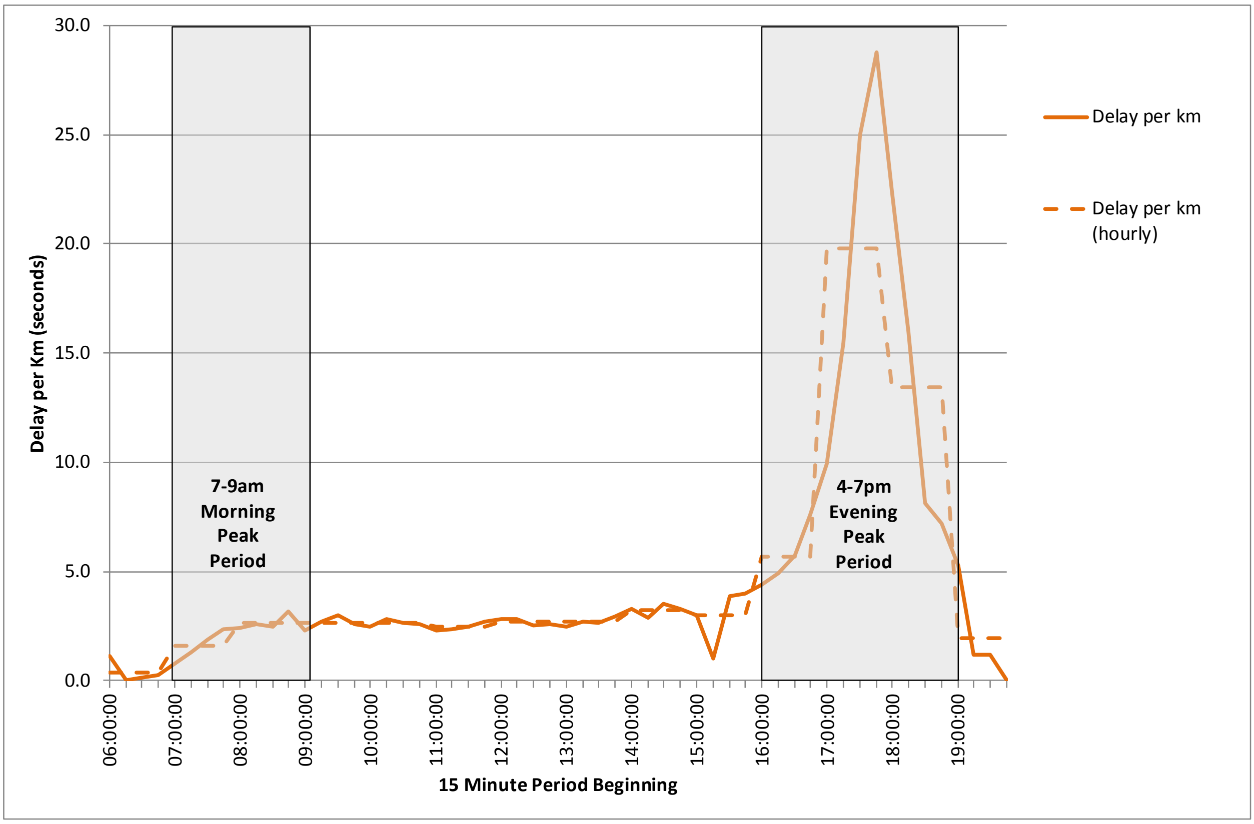
To calculate minutes of delay per km it is necessary to compare the actual travel time recorded with an expected free-flow travel time. Free-flow travel times can be generated using the speed limit; however, the speed limit does not necessarily reflect variations in the road environment, terrain and traffic control. Travel times from floating car surveys could be used but these have limited coverage compared with the coverage provided by GPS and Bluetooth data.

It is therefore proposed that a measure of *minimum average traversal time* should be used to represent the expected travel time at an uncongested time of day. While travel behaviour and the underlying trip purposes can differ considerably between congested and uncongested times of day, this is considered to be a generally robust approach. In a built-up environment, traffic signals may well experience different cycle times and phase splits in uncongested conditions, and impedance due to pedestrian crossings. PT activity would further influence the minimum average travel times calculated.

Minimum average traversal time is extracted for each link by examining the digital data to find the hourly period with the lowest recorded traversal time. To ensure this value represents a reasonable minimum traversal time, only hourly periods providing an average traversal time across a minimum of three sample counts should be examined, and the speed required to achieve this time capped at the posted speed limit.

The same example from figure 6.2 is repeated here to demonstrate this indicator in application. The fastest average travel time (representing the average of 15 minutes of continuous data) was recorded between 6:15am and 6:30am and corresponded to 89km/h despite the 100km/h posted speed limit (figure 6.4).

Figure 6.4 Example of minute of delay per km



6.1.4 Minutes of delay per km (PT) (NP2.2)

This indicator is generated from the output of NP1.3 average travel time (PT), as outlined in section 6.1.2. The methodology discussed in section 6.1.3 for generating minimum average traversal times has also been followed.

Compared with the calculation of minutes delay per km for private transport modes, this indicator is prone to error and miscalculation as:

- it is difficult to cap the minimum average traversal times at the speed limit for each link due to a lack of high-quality speed limit data, which also needs to be weighted for some corridors
- it is expected that the creation of routes between stops using the 'shortest path' may not follow the actual route, resulting in inaccurate corridor length values
- the variable quality of PT GPS data affects travel-time values.

The quality and accuracy of the outputs were tested as part of the proof-of-concept model (see chapter 8).

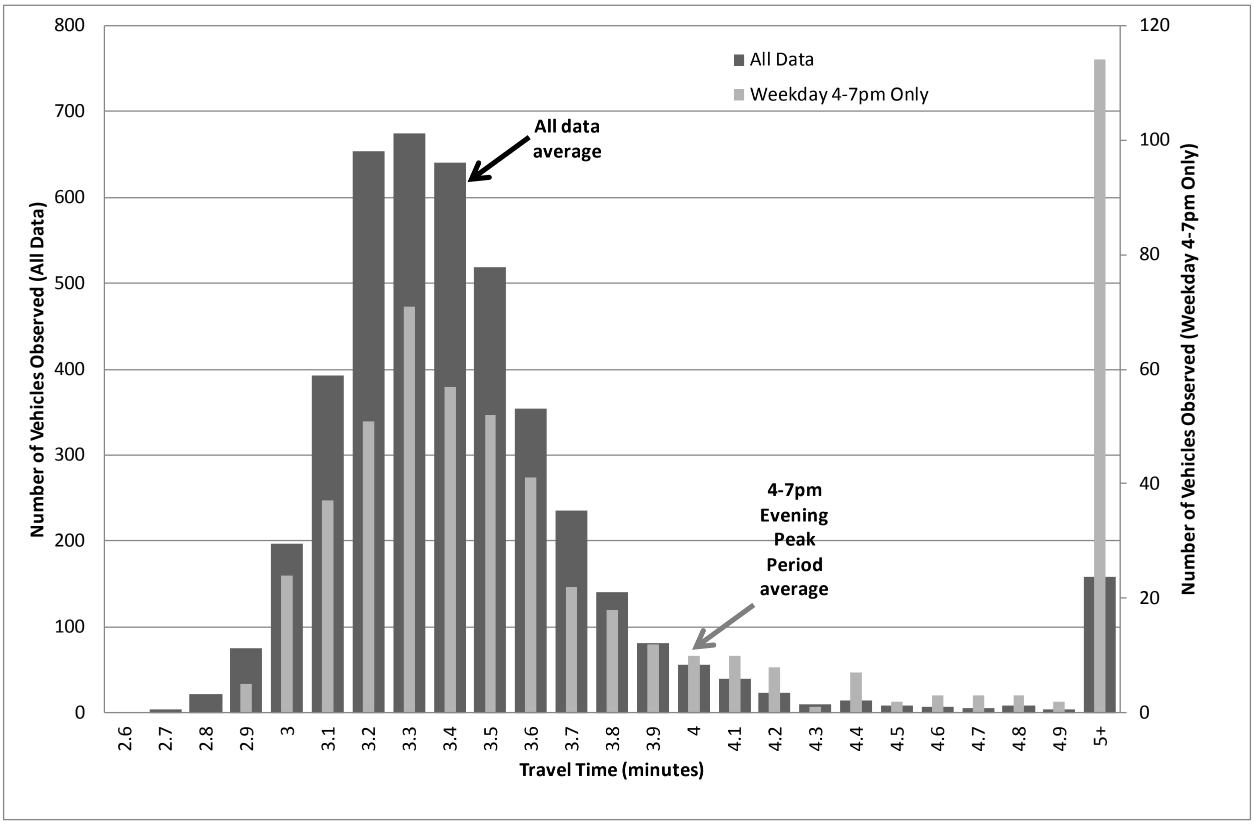
6.1.5 Travel time reliability – standard deviation and percentile speeds (NP3.1 and NP3.3)

The majority of digital data suppliers in New Zealand did not specifically calculate standard deviation to measure variability about average data, instead producing minimum, maximum and percentile data to represent measures of variability.

The analysis assumes the data is normally distributed about the mean, therefore one of the datasets which includes travel times for individual vehicles is plotted as a histogram (figure 6.5**)** to understand the underlying distribution of the vehicular travel times. The data in figure 6.5 corresponds to a month of observations on a motorway section of SH1 in Auckland and is plotted for all vehicles irrespective of the day of the week and time of day. A separate data set is also presented whereby the full data set is filtered to include only those vehicles travelling during the congested weekday evening peak (4pm to 7pm).

It is evident that the data is skewed about the mean (which is 3.46 minutes for all vehicles and 4.06 minutes for vehicles travelling between 4pm and 7pm on weekdays) with a large number of vehicles with travel times in excess of five minutes especially during the weekday evening peak period. This skewed distribution implies that it is likely to be inappropriate to use standard deviation as a measure of travel-time reliability and that percentiles may indeed be a more appropriate indicator.

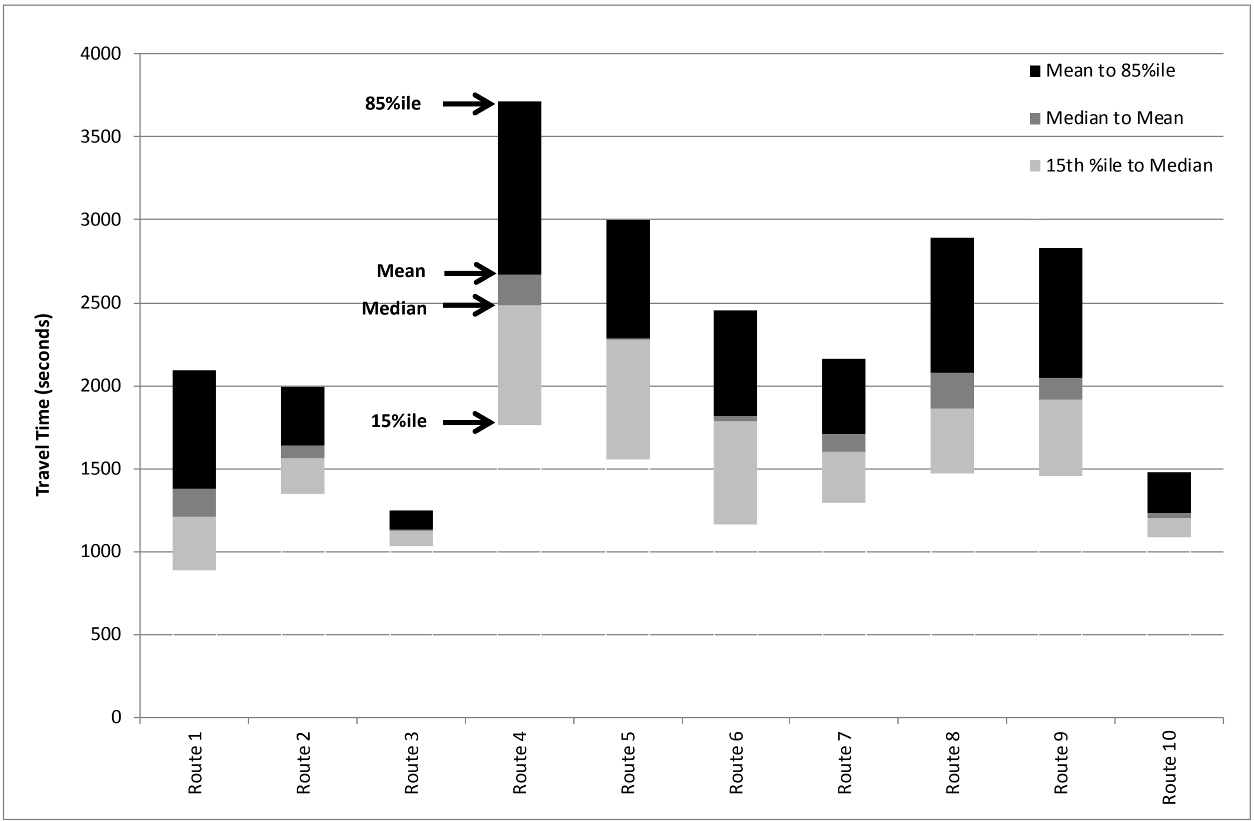
Figure 6.5 Distribution of travel times on SH1 motorway corridor



To further understand the relationship between the mean, median and percentile travel times during peak periods, a selection of 10 routes across the Auckland SH1, SH16 and SH20 networks was analysed including both morning and evening peak data, as presented in figure 6.6. In every instance the mean travel time exceeds the median travel time, in some cases by as much as 10% of the mean travel time. The mean travel time is situated approximately midway between the 15th and 95th percentile travel times whereas the median is invariably skewed towards the 15th percentile.

It is recommended that the mean (as opposed to the median) remains an appropriate measure of the expected travel time for road segments and the percentiles provide a more reasonable representation of travel-time reliability instead of standard deviation on the SH network.

Figure 6.6 Comparing the mean, median and percentile travel times



6.1.6 Variation from speed limit (NP4)

The methodology for calculating variation from speed limit is simply a matter of subtracting the known posted speed limit from the average speed recorded. For road links where the speed limit changes, a weighted average speed limit value is required.

6.1.7 Traffic flow (NP5)

6.1.7.1 Calculating traffic volume from GPS data

To understand how reliably the AADT or hourly volumes can be estimated from GPS data, 20 SH road segments which correspond to count station locations were compared with the published AADT volumes for 2012 from NZ Transport Agency (2013c). The chosen sites included urban and rural locations in and around Auckland, Hamilton, Tauranga, Wellington and Christchurch metropolitan areas.

In each instance a month of GPS sample data (February 2013) was analysed to extract a daily average number of sample data records. This was compared with the corresponding 2012 AADT as shown in table 6.2. The expected sample rate for this dataset was 2.1% of the full traffic flow, making it the highest sample rate of the GPS suppliers.

Table 6.2 GPS sample rates at 20 sites

Region	Location	Transport Agency site ID	AADT	GPS sample count	Sample rate
Auckland	SH16 Patiki Rd to Te Atatu Rd	ID:01610010	95,780	1,925	2.0%
	SH18 Upper Harbour Bridge	ID:01810007	34,750	179	0.5%
	SH1 Auckland Harbour Bridge	ID:01N00424	157,322	3,064	1.9%
	SH1 Takanini to Papakura	ID:01N10456	74,116	8,887	12.0%
	SH20 Puhinui Rd to Massey Rd	ID:02000006	58,625	9,187	15.7%
Bay of Plenty	SH2 north of Kairua Rd	ID:00200168	22,271	3,381	15.2%
	SH2 Takitumu Drive	ID:00210152	31,155	1,787	5.7%
	SH29 260m before Route K roundabout	ID:02900019	14,643	473	3.2%
Waikato	SH1B 500m past Gordonton Rd/Taylor Rd Intersection	ID:01B00015	3,035	165	5.4%
	SH1 410m north of Rifle Range Rd/Avalon Drive RAB	ID:01N00549	17,003	934	5.5%
	SH1 50m east of Cobham Dr Bridge	ID:01N00555	26,214	531	2.0%
	SH26 875m west of Lissette Rd	ID:02600002	5,849	133	2.3%
Wellington	SH2 north of Petone Interchange	ID:00210974	39,158	433	1.1%
	SH1 between Whitford Brown and Porirua Nth	ID:01N11052	51,998	738	1.4%
	SH1 between SH2 junction and Aotea Quay	ID:01N11069	86,054	2,007	2.3%
	SH58 Pauatahunui east	ID:05800009	13,605	574	4.2%
Canterbury	SH1 Christchurch – Johns Rd east of Sawyers Arms Rd	ID:01S00337	21,092	941	4.5%
	SH73 Yaldhurst Rd west of SH1	ID:07300015	12,168	452	3.7%
	SH74 QE II Drive east of Main North Rd	ID:07409008	18,392	376	2.0%
	SH74 Dyers Rd south of Linwood Avenue	ID:07409018	11,958	128	1.1%
All sites			795,188	36,295	4.6%

The sample rates varied considerably for each corridor. Within Auckland alone, sample rates varied between 0.5% and 15.7%. There was no identifiable correlation between the volume of traffic and the sample rate. Further interrogation also revealed no relationship between the percentage of heavy vehicles at the corresponding count site location and the sample rate.

Consultation with suppliers revealed the variation was largely a function of the business activities of the commercial vehicle fleets recorded through GPS data supply contracts. Suppliers of GPS data were unable to provide guidelines as to the fleet composition or activities of the vehicles from which data was collected. Data suppliers stated that the majority of the data they received was collected from commercial vehicle fleets and in some instances was exclusively associated with commercial and not private travel. In addition, as data supply contracts changed it was likely that the resultant sample rate would change.

Without a better understanding of fleet composition, it cannot be determined at this stage whether data collected from GPS technology based sources is representative of the composition of the entire vehicular fleet on the SH network unless individual vehicle classes can be isolated in the data supplied.

One of the GPS data providers supplied the research team with travel time and speed data broken down by vehicle class although the overall fleet composition was heavily biased towards medium and heavy commercial vehicles with low sample rates for light vehicles. As a result of this bias, the dataset was not considered to be a reliable source of estimating traffic volumes or VKT for the SH network; however, it was considered as a source of heavy vehicle VKT.

6.1.7.2 Calculating traffic volume from Bluetooth data

The sample rates of Bluetooth data were significantly higher than GPS at around 15% to 18% of the total flow, according to the data suppliers. Our preliminary assessment indicated sample rates were at least 12% of total flow. An assessment of sample rates of Bluetooth data in relation to Bluetooth monitoring on the Waikato Expressway (Beca 2013) found that sample rates were approximately 15% of the full traffic volume. The analysis concluded that Bluetooth sample rates tended to be relatively static during the day and week to week. The detector sample count could therefore be used to estimate traffic counts at that location with some degree of reliability.

Current Bluetooth technology cannot provide a break-down of vehicle composition. As Bluetooth sensors register devices rather than individual vehicles, no information is gathered about the characteristics and there is a risk that unknown devices not associated with vehicle movements may be considered in any analysis, especially in urban areas. Therefore it is not recommended that the number of Bluetooth devices recorded by a sensor be used to approximate traffic volumes at a single point, although it may be possible to estimate traffic volumes on a corridor as a function of the number of matches between adjacent Bluetooth sensors.

Examples from multiple suppliers were used to test the appropriateness of calculating traffic volumes and VKT from matched Bluetooth sensor data.

Example one – SH1 motorway (Khyber Pass Road to Saint Marys Bay)

For this example, a month of data for 3.4km of SH1 in Auckland was analysed (Khyber Pass Road to Saint Marys Bay). Traffic counts for this route are available from the Transport Agency telemetry site ID:01N29427 with 33,510 vehicles per day expected along this corridor (NZ Transport Agency 2013c). Between 5am and midnight, the average number of Bluetooth matches on this corridor was 3,799. Following seasonal adjustment and expansion to represent a full day, the adjusted number of matches grew to 3,890, which is 11.61% of the corresponding AADT. By applying this rate a factor could be calculated (ie 1/.1161 = 8.613) to expand Bluetooth data matches at this location to estimate AADT from future datasets.

In this instance, the total VKT for the corridor could be estimated by multiplying the AADT by the length of the corridor (ie 33,510 * 4.3 = 144,000 VKT per day or 52.6 million VKT per annum). There are a number of northbound off ramps along this 4.3km corridor and depending on whether through or all traffic is required for a particular assessment, the total VKT on the corridor may need to account for non-through vehicles. This could be made possible if the corresponding ramps were also installed with sensors or could be estimated by analysing the corresponding ramp volumes from AADT counts and distance between ramps and adjusting the through traffic results accordingly.

Example two – Lunn Avenue/Abbots Way to Ellerslie Panmure Highway/Mount Wellington Highway

While this example is not part of the SH network, it was included to demonstrate how Bluetooth data can be used to estimate traffic volumes and VKT in urban environments. The corridor in this example is eastbound from Lunn Avenue/Abbots Way to Ellerslie Panmure Highway/Mount Wellington Highway in Auckland and is 1.6km in length. A total of 2,270 matches were recorded over a five-day period in February 2013 between 6am and 7pm, an average of 454 per day. Expanding the match data to include traffic volumes outside of these hours at the local count site, and to account for seasonality at the nearest Transport Agency telemetry site, an estimated 575 matches per weekday were compared with a five-day AAWT count of 9,608 on Lunn Avenue (Auckland Transport 2013a). The number of Bluetooth matches along this corridor was 6.0% of the traffic count with the corresponding expansion rate being (1/.0599 = 16.699).

The total VKT for through traffic on this corridor can then be estimated by multiplying the AADT by the length of the corridor (9,608 * 1.6 = 15,400 VKT per weekday). As this is an urban application there are high-volume turning movements on and off this corridor for non-through traffic and a number of local roads accessing both Lunn Avenue and the Ellerslie Panmure Highway. More detailed analysis across multiple sites could provide a more comprehensive picture of VKT in this vicinity including other key traffic movements, but would not account for additional VKT due to side friction.

6.1.7.3 Detailed methodology for estimating vehicle counts from Bluetooth data

Having established the relationship between the match rate and actual traffic volumes, Bluetooth data can then be used to monitor changes in these indicators as a direct result of background traffic growth, changes in road infrastructure, traffic management or travel demand management.

In addition to the limitations on the methodology noted in the preceding examples, Bluetooth match rates may also vary depending on where the detectors are installed. Sample and expansion rates should therefore be calculated for each matched pair of sensors. Variations in match rates between Bluetooth detectors are expected as the fleet composition varies between corridors. On this basis it is recommended that Bluetooth data be used to infer traffic volumes, but a monitoring framework should support this to regularly review the expansion sample rates for each corridor from which volumes are analysed.

All-day traffic flow data by road segment is recorded in RAMM and is included as an attribute within the Critchlow CAS road centreline used in the proof-of-concept model development. For SH applications, the AADT values in the CAS centreline were interpolated from Transport Agency count data (NZ Transport Agency 2013c). AADT values for local roads were provided by local authorities through RAMM and the dates for these counts varied.

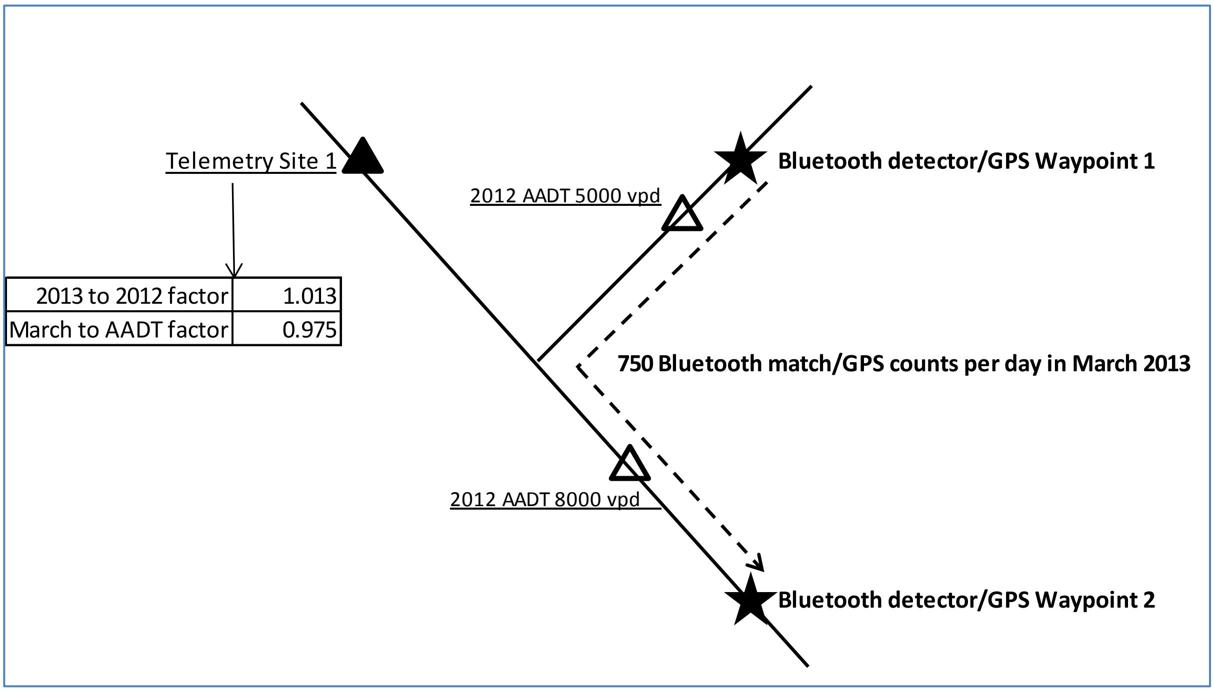
The traffic flow corresponding to Transport Agency AADT data was filtered out for road segments corresponding to the count sites. These count values formed the basis for calculating the expansion factors from Bluetooth matches to total traffic volumes. The specific steps for each Bluetooth route with reference to the example shown in figure 6.7 are as follows:

1. Identify the known count location(s) and corresponding directional AADT volume along the surveyed route. (In figure 6.7 there are two counts with directional AADT recorded in 2012 of 5,000 vehicles per day (vpd) and 8,000 vpd respectively.)
2. Calculate a weighted average AADT based on break points along the route. (In this instance the two sections are equidistant and therefore the weighted average is 6,500 vpd.)
3. Determine the unadjusted sample rate which is the number of matches or sample counts per day divided by the weighted average AADT. (In this example, 750 matches per day in March 2013 compares with a 2012 AADT of 6,500 which is an 11.5% unadjusted sample rate and expansion factor of 1/.115 = 8.67.)
4. Determine the annual and seasonal adjustment factors by:
   a. locating the closest Transport Agency telemetry site location from the midpoint of the route

b looking up the annual and seasonal adjustment factors corresponding to the nearest telemetry site. (In this example, the annual adjustment factor to convert from 2013 back to 2012 is 1.013 and seasonal adjustment from March to average annual results is 0.975.)

5 Calculate seasonally adjusted sample rate and expansion factor (In this instance 11.5%/(1.013 * 0.975) is 11.7% which is a seasonally adjusted expansion factor of 1/0.117 = 8.56).

Figure 6.7 Example calculation of expansion factors



The estimated count based on an expanded number of Bluetooth matches is higher than the night-time Transport Agency telemetry site counts and lower during the day. This could be due to the Bluetooth technology recording a higher proportion of through trips overnight as a result of more long-haul commercial vehicle trips. Conversely there are a smaller proportion of through trips being recorded as Bluetooth matches during the day as the number of long-haul through trips is disproportionately lower.

To take into account this bias a day and night factor was introduced. These factors were calibrated from the data presented in figure 6.8 and are as follows:

- Night factor applies to hours beginning 10pm to 4am: *adjusted estimated hourly volume* = 0.6 x *estimated hourly volume.*
- Day factor applies to hours beginning 7am to 8pm: *adjusted estimated hourly volume* = 1.16 x *estimated hourly volume.*
- No change outside these hours.

The modelled hourly count profile with the inclusion of day and night factors is included in figure 6.9 which clearly improves the fit against Transport Agency telemetry site data.

Figure 6.8 Comparison of Bluetooth matches and Transport Agency survey counts

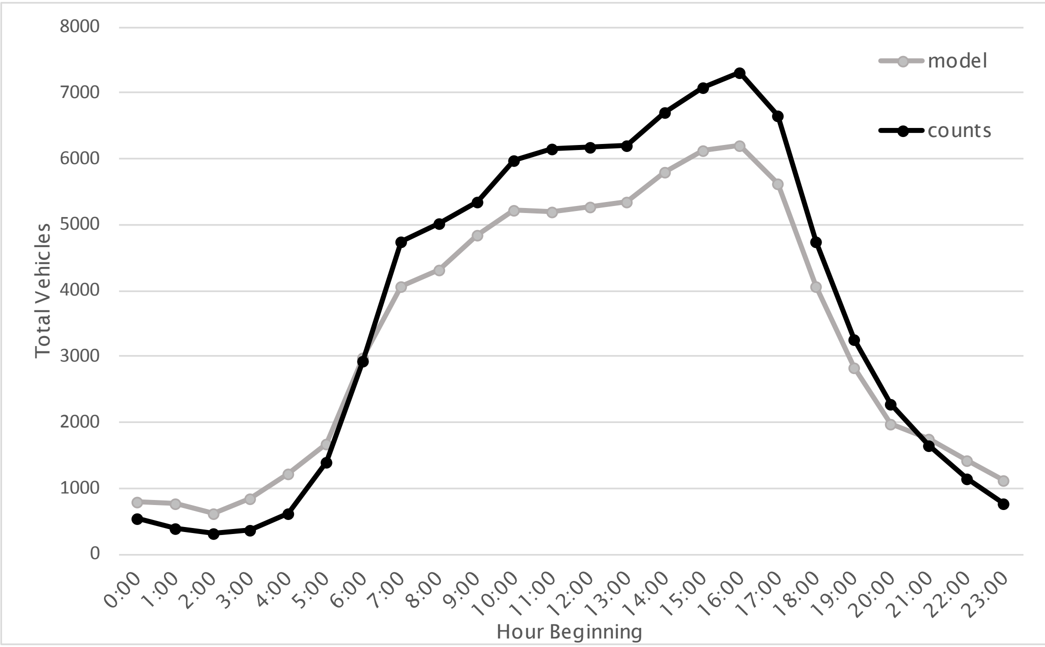
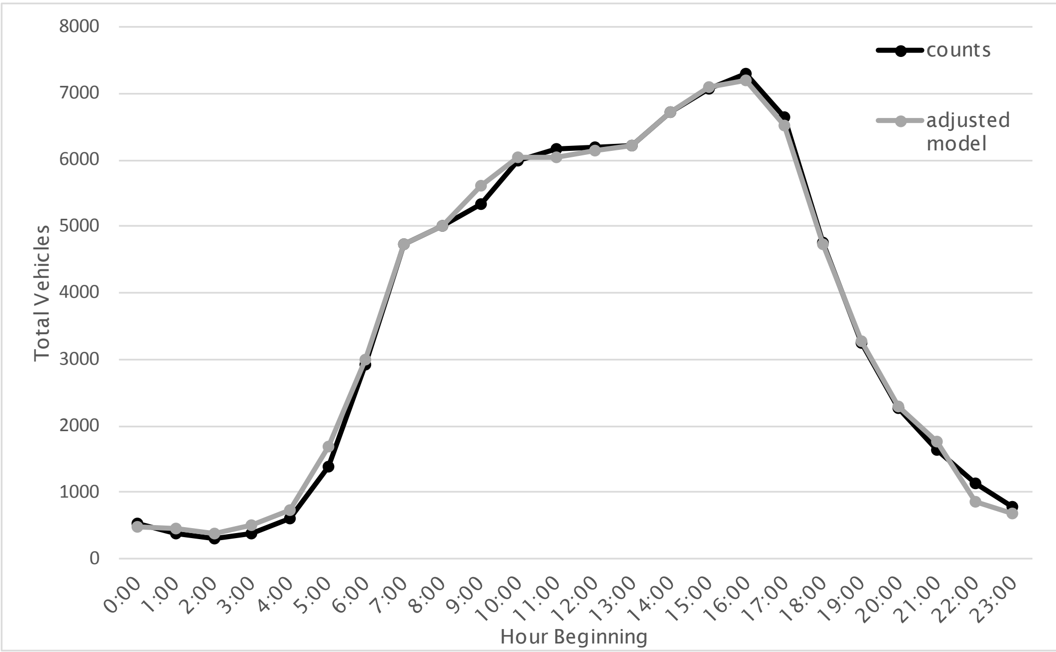


Figure 6.9 Comparison of Bluetooth matches and Transport Agency survey counts – with day/night adjustment



The methodology specified here for SH applications can also apply to non-SH Bluetooth applications where published AADT counts are available in the RAMM dataset and CAS road centreline data. In the same way the sample rate is adjusted to take into account the year, and seasonal trends for SHs, local road counts can be annually and seasonally adjusted to determine an AADT to match the SH dataset. This can also be done by locating the nearest urban or rural (as appropriate) SH telemetry site and using this site's seasonal profiles.

6.1.8 Emissions – CO, N_2O, PM_{10} and VOC (HE1.1-HE1.4)

The concentrations of CO, N_2O, PM_{10} and volatile organic compounds (VOCs) were calculated using the procedures in section A9.3 of the EEM. These procedures were developed from the MoT vehicle fleet emissions model and used to calculate ambient emission loads for each road segment and time period (in grams).

This calculation requires traffic volume, fleet composition and average speed values. The emission rate calculations determine the number of grams per VKT using a quadratic equation:

$$\textit{Emissions (g/VKT)} = AS^2 + BS + C$$

Where:

- *S* is the average speed for the road segment over the period
- *A,B,C* are constants defined in the EEM (refer table 6.3).

To demonstrate this calculation, the example in section 6.1.7.2 (SH1 between Khyber Pass Road and Saint Marys Bay) has been revisited. The observed average speed on this corridor was calculated from Bluetooth data as 83km/h and VKT was calculated as 144,000 vehicle km per day. While both of these inputs have been derived from the Bluetooth data, the methodology outlined in the EEM also requires the percentage of heavy vehicles on the corridor. As discussed in section 6.1.7.2 it is not possible to estimate heavy vehicle flows from Bluetooth data. For this example the percentage of heavy vehicles has been taken from the corresponding Transport Agency count site (ID:01N29427) which is 3.9% on this corridor (NZ Transport Agency 2013c). The outputs are presented in table 6.3 for all four emissions for a typical day.

Table 6.3 Emission rates for SH1 Khyber Pass to Saint Marys Bay northbound through traffic

Emission	Vehicle	A	B	C	Emission g/VKT	Fleet emission (g/VKT)	Total daily emission (kg)
CO	Light	0.0036	-0.545	25.5	5.07	4.97	716
	Heavy	0.000647	-0.11	7.31	2.64		
N_2O	Light	0.000246	-0.0287	1.67	0.98	1.28	184,433
	Heavy	0.00204	-0.275	17.4	8.63		
PM_{10}	Light	0.0000245	-0.00342	0.153	0.04	0.10	13,700
	Heavy	0.000382	-0.0455	2.65	1.51		
VOC	Light	0.000553	-0.081	3.55	0.64	0.63	91,286
	Heavy	0.000307	-0.0584	3.3	0.57		

It is evident that emission rates can be calculated directly from speed and VKT data derived from Bluetooth matched data, but ideally they also require supplementary information about the mix of light and heavy vehicles in the fleet. If the fleet composition cannot be discerned from a digital dataset, the typical light and heavy vehicle fleet composition could be assumed by referring to classified traffic counts in the vicinity.

There is an air quality monitoring station located at Khyber Pass, and it is feasible that estimated values could be compared against actual values to validate the emission rate outputs. Additionally, WiM data could also provide a break-down of vehicle types by ‘light’ and ‘heavy’ for road corridors located near WiM sites.

6.1.9 Carbon dioxide emissions (HE2)

Carbon dioxide (CO_2) emissions for a road segment were estimated using Transport Agency guidelines specified in section A9.7 of the EEM (NZ Transport Agency 2013b). The number of tonnes of CO_2 is directly proportional to the vehicle operating costs on that road segment, where CO_2 costs are 4% of vehicle operating costs for the corresponding road segment and can be converted to tonnes using a value of $40/tonne. Cost indicators including the derivation of vehicle operating costs from emerging data sources are discussed in section 6.1.13. The Transport Agency guidelines to calculating CO_2 emissions can simplistically be implemented within the proof-of-concept model if vehicle operating costs can be reliably calculated from emerging data sources.

6.1.10 VKT by star rating (S1)

Star rating values were sourced from KiwiRAP assessment tool (KAT) which covers most (but not all) of the rural SH network (KiwiRAP 2010a). Given sufficient Bluetooth coverage of the SH network it is possible to aggregate the VKT to provide a meaningful indicator of the percentage of travel by road assessment rating for an entire region, and potentially on a nationwide basis.

Based on an analysis of KAT data, only those roads with substantial (>80%) KAT coverage were processed for this indicator. This 80% threshold value takes into account both the proportion of rural and non-rural road environment along a link and the KAT coverage for the rural environment. For example the 80% threshold would be reached by a 100% rural road link with 80% rural KAT coverage, or an 80% rural road with 100% rural KAT coverage.

6.1.11 Vehicle km travelled (A1)

The traffic volume for a road segment can be estimated using the methodology outlined in section 6.1.7. To calculate the total VKT, the estimated traffic volume can simply be multiplied by the distance of the corresponding road segment.

6.1.12 Total freight tonne-km travelled (A2)

While Bluetooth data can be used to estimate traffic volumes and VKT across the SH network (where sensors are available) it is not possible to isolate heavy vehicles from the matched Bluetooth data, other than by assuming a fixed percentage based on traffic count data. GPS data sources that can be broken down by vehicle class can be used to estimate heavy vehicle VKT on the SH network applying a similar methodology to that presented in section 6.1.7. However, it is important to note that as with any GPS data sources, the underlying sampling rates may vary significantly from road segment to road segment and therefore the calculation of expansion factors should be carefully considered. This approach was tested during the research and is documented in section 8.1.3.

As an alternative approach, if coverage for WiM technology extends in the future beyond the current six isolated sites, there may be potential to couple the freight input data from WiM stations with VKT data from Bluetooth sources to estimate heavy VKT on the network. To explore the feasibility of combining WiM and Bluetooth network data to estimate a freight tonne km indicator it would be necessary to have multiple WiM stations covered within a continuous Bluetooth coverage area. There are presently no geographic areas with this level of coverage of both technology types in New Zealand.

The heavy vehicle km calculated from GPS medium and heavy vehicle data can be converted to freight tonne km for road freight transport, assuming an average freight load of 7.07 net tonnes per HCV vehicle taken from MoT's vehicle fleet statistics (MoT 2012b).

6.1.13 Cost per km travelled and total cost of travel (C1.1–C1.2)

The cost per km travelled comprises fixed and variable costs of personal travel and can be evaluated for vehicle drivers from speed and travel-time information sourced from GPS and Bluetooth data sets.

The cost of travel for the vehicle driver mode can be measured as the average speed of travel on road segments and can be transformed into a base cost for urban and rural SH corridors using the tables provided in section A5.7 of the EEM. This can be further refined where road segments are defined as urban or rural, and as arterial or non-arterial. The resultant vehicle operating cost per km can be expanded to represent all traffic based on volumes estimated from Bluetooth data.

The base value travel time can also be calculated based on the procedures outlined in section A4.3 of the EEM. While vehicle operating cost represents the costs associated with the vehicle, travel-time costs represent the costs associated with vehicle occupant's time including both private and commercial vehicle use. A base value of travel time is specified in table A4.1 of the EEM for urban and rural roads and for various time periods. Road user costs (RUC) associated with vehicular travel along a road segment can be calculated by adding the travel-time costs to the vehicle operating cost.

The two examples from section 6.1.7.2 have been revisited to demonstrate calculations on each road corridor for a single vehicle km, and then expanded to include all traffic traversing the corridor. These examples differ from those presented in previous sections in that they correspond to both directions of travel for each corridor. The vehicle operating cost base values published in the EEM include provision for road gradient and represent the average of both increasing and decreasing gradient hence the analysis is intended for two-way cost evaluations (NZ Transport Agency 2013b).

6.1.13.1 Example one – SH1 motorway (between Khyber Pass Road to Saint Marys Bay)

This analysis corresponds to a month of data on SH1 travelling between Bluetooth sensors adjacent to Khyber Pass Road and at Saint Marys Bay, a corridor 4.3km in length with an average gradient of 2%.

The average speed profiles collected in 15-minute increments were analysed to determine the percentage breakdown of travel by speed for vehicles travelling in both the northbound and southbound directions. The output of this analysis is presented in table 6.4. The base vehicle operating cost values correspond to the costs for urban arterial corridors with a gradient of 2% from table A5.7 of the EEM.

Table 6.4 Base vehicle operating cost analysis of SH1 Khyber Pass to Saint Marys Bay

Average speed (km/h)	Number of vehicles	%age of vehicles	Base vehicle operating cost (cents/km)
10	85	0.1%	50.5
15	223	0.1%	44.5
20	539	0.3%	40.1
25	721	0.4%	36.8
30	524	0.3%	34.4
35	765	0.5%	32.7
40	485	0.3%	31.5
45	1773	1.1%	30.7
50	524	0.3%	30.2
55	728	0.4%	29.9
60	1118	0.7%	29.9

Average speed (km/h)	Number of vehicles	%age of vehicles	Base vehicle operating cost (cents/km)
65	1119	0.7%	30.0
70	1197	0.7%	30.3
75	4463	2.7%	30.7
80	42,907	26.3%	31.1
85	89,902	55.1%	31.7
90	15,294	9.4%	32.4
95	801	0.5%	33.1
100	26	0.0%	33.8
105	0	0.0%	34.7
110	1	0.0%	35.5
Average vehicle operating cost per km of travel for corridor			31.6

The base vehicle operating cost for traffic on this corridor is $0.316 per vehicle km or $1.359 for a single vehicle traversing the 4.3km corridor. The total VOC aggregated across all traffic can be calculated by multiplying this figure by the VKT of travel in both directions which is 299,670 VKT per day (69,670 two-way AADT count multiplied by the 4.3km corridor length). The corresponding vehicle operating cost for two-way through traffic is $94,700 per day or $34.55 million per annum. These values are specified in July 2008 dollars and the EEM provides factors to update these to the relevant year of costs.

The base value of travel time for an urban arterial corridor across all time periods is specified in table A4.1 of the EEM as $16.27 per hour (in July 2002 dollars). The average travel time sourced from the month of Bluetooth data collected is 3.15 minutes (or 0.0525 hours) northbound and 3.17 minutes (or 0.0528 hours) in the southbound direction. The average travel-time cost for a single vehicle traversing this corridor is then $0.854 northbound and $0.859 southbound, corresponding to $0.199 per km northbound and $0.200 per km southbound. As with vehicle operating cost calculations, the travel-time costs can be expanded to represent all traffic using the AADT vehicle count. Aggregated across both directions of travel for the entire corridor, this corresponds to $57,980 per day or $21.16 million per annum. The travel-time values specified here are in July 2002 dollars and table A12.3 of the EEM provides factors to update these to the relevant year of costs.

The total cost per km travelled can then be estimated by adding the vehicle operating and travel-time costs, and applying the relevant update factors (in this case 1.06 for vehicle operating costs and 1.37 for travel-time costs to bring them up to July 2012 dollars). This equates to $0.608 per km in northbound and $0.609 per km in the southbound direction in July 2012 dollars.

As in the example in section 6.1.7.2 it is reiterated that these figures correspond to the through traffic component only. In this example, the total VKT and vehicle operating cost calculations could be expanded to include on and off ramp traffic if the corresponding ramps were also installed with sensors. Alternatively, costs associated with non-through traffic could be estimated by analysing the corresponding ramp volumes from AADT counts and the distance between ramps.

6.1.13.2 Example two – Lunn Avenue/Abbots Way to Ellerslie Panmure Highway/Mount Wellington Highway

While this example is not on the SH network it has been included to demonstrate the application of Bluetooth data to estimating vehicle operating costs in congested urban environments. The corridor in this example is an urban arterial from Lunn Avenue/Abbots Way to Ellerslie Panmure Highway/Mount Wellington Highway in Auckland. It is 1.6km in length and has an average gradient of 2%.

Applying the same methodology, the average base vehicle operating cost is 15% higher than that in the first example at $0.364 per km due to the slower urban speed environment; however, the travel-time costs three times higher than in the motorway environment, at $0.576 per km eastbound direction and $0.644 per km in the westbound direction. The resulting total cost per km (in July 2012 dollars) is significantly higher than the values calculated in the first example at $1.175 and $1.268 per km for eastbound and westbound travel respectively. This is representative of the significantly slower speed environment and level of congestion on this corridor.

Other vehicle operating cost components due to excessive congestion, bottleneck delay and speed change cycles are more difficult to incorporate based on the data available from emerging data sources as the GPS and Bluetooth data samples relate to longer road segments rather than to specific locations at which speed and delay can be isolated at the micro-level. These additional vehicle operating cost components are not included in the cost model, which causes a significant limitation. By way of example, using the methodology in this section, an uncongested urban arterial operating at 50km/h with a 50km/h free-flow speed would be attributed the same cost as a congested urban arterial operating at 50km/h with a free-flow speed of 80km/h. It is possible that the minutes of delay per km indicator could be used to estimate the extent of congestion and this in turn could become the basis for calculating vehicle operating costs due to these components.

6.1.14 Cost per freight tonne km and total cost of freight travel (C2.1and C2.2)

The total fixed and variable costs of road freight transport can be calculated per freight tonne or per freight tonne km using EEM RUC data associated with commercial vehicle activity. There are no areas on the SH network where continuous Bluetooth coverage overlaps multiple WiM sites to enable freight tonne km to be estimated for road freight transport. However commercial GPS data which can be isolated by vehicle class can be used to calculate total freight tonne km for medium and heavy commercial vehicle classes as described in section 6.1.12.

The travel-time costs can be assumed from table A4.1 and table A4.2 of the EEM for vehicle occupant and vehicle and freight base travel-time values respectively. The base vehicle operating costs can also be taken from tables A5.3 through A5.7 of the EEM, and added to the corresponding travel-time costs for a road segment to calculate the total road user costs for heavy vehicles. These in turn can be converted to cost per freight tonne km through the application of an average freight loading factor (as described in section 6.1.12).

6.2 Additional data requirements

Many of the indicators identified required additional data (both spatial and non-spatial) to enable their successful and accurate calculation. A discussion of some of these data sources follows.

6.2.1 Road centrelines

Data is required to generate road centreline links for each digital data source and it is proposed that the Critchlow road centrelines are used for this purpose. This data is used by the Transport Agency for the Crash Analysis System (CAS) and is one of the most comprehensive road centreline datasets available in New Zealand. Attributes associated with this dataset include road name, posted speed limit and hierarchy. Flow values by road segment are also included in this dataset, originally sourced from the RAMM database. These flow values are used in conjunction with Transport Agency count sites and Bluetooth counts to estimate traffic volumes across a road network (see section 5.5.1.3 for a description of this methodology).

The road centreline can be segmented where necessary to match GPS way point locations or Bluetooth detector locations to improve the accuracy of mapping the digital data. This is particularly important for fine-grained GPS data sets including those used to define travel times between PT stops.

6.2.2 Road safety data

The indicator S1 'Road assessment rating – VKT per star rating' requires a measure of road safety rating known as the road protection score (RPS) from KiwiRAP (KiwiRAP, 2010b). RPS scores are calculated for every 100m section of the rural SH network and reflect the degree of safety hazard (or risk) that exists due to the design of the road. The most recent RPS score data (2012) has already been mapped against the SH road centreline for the Transport Agency's SafetyNet webmap viewer and is available for this research.

6.2.3 Digital elevation model (DEM)

A digital elevation model (DEM) is a spatial 3D model of ground surface elevation. Using a DEM and GIS spatial analysis tools, it is possible to extract spot heights and estimate the average gradient along a road segment. One DEM that is available for use is the Landcare Research 25m resolution DEM for the entire country. This DEM is freely available for use under the Landcare Data Use Licence (Landcare 2012) and this has been used to calculate gradient in the development of the proof of concept model.

6.2.4 Transport Agency AADT data

Data from the Transport Agency published count data is used to calculate the expansion factors and to check the AADT values recorded on the CAS centreline. Count data is released annually and is available in NZ Transport Agency (2013c).

6.2.5 Road freight loading

WiM data records each vehicle and includes the vehicle type based on the axle configuration, vehicle length, speed and weight (by axle and gross weight) as well as the specific time the vehicle crossed the station. This data could potentially be used to determine the average freight loading for MCV, HCV1 and HCV vehicles classes, however as WiM measures the gross weight as opposed to net weight, some allowance would need to be made for the average unloaded vehicle weight for each class.

As a simpler alternative it is proposed that the average weight loading be sourced from the MoT's vehicle fleet statistics (MoT 2012b). The most recently published figure (for the year 2011) corresponds to an average weight loading of 7.07 tonnes per heavy vehicle. This figure has been derived based on an unpublished methodology developed by the independent transport research organisation, TERNZ. The methodology assumes that truck loads are on average 50% of the licence weight with a 55% loading factor, and trailer loads are 75% of the licence weight with a 45% load factor. The average loading of 7.07 tonnes will be assumed in the proof-of-concept model and can be multiplied by the heavy vehicle VKT to derive a measure of road freight tonne km on the SH road network.

The MoT is currently in the process of evaluating how the Transport Agency WiM data can be used to estimate typical weights by vehicle class. When this work is complete and has been approved, it will supersede the TERNZ methodology and provide a valuable input to the calculation of freight tonne km within this research.

7 Proof-of-concept model development

7.1 Introduction

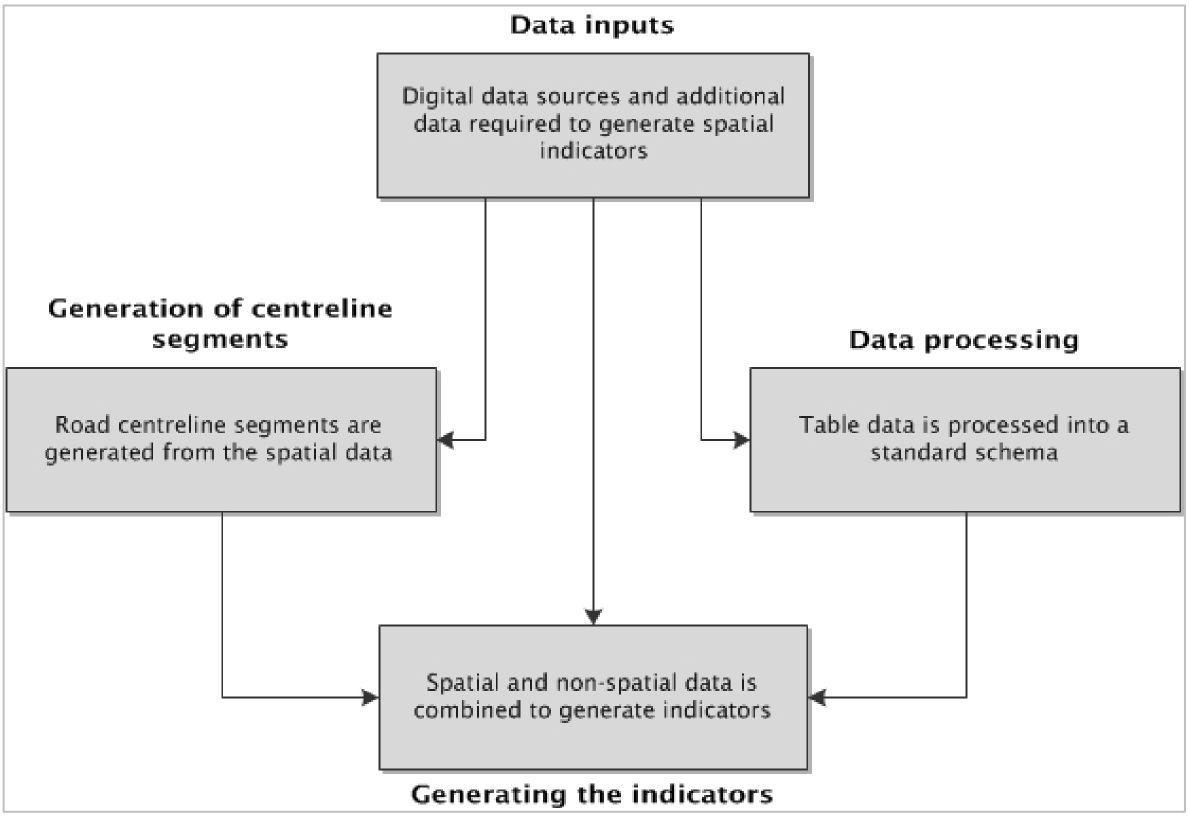
This chapter outlines how the proof-of-concept model was developed to demonstrate how the set of 23 indicators could be generated from the Bluetooth and GPS technologies in a mix of urban and rural environments. This chapter also outlines the database framework and GIS model structure for the proof-of-concept model.

Figure 7.1 provides a high-level view of the database framework which was applied to each of the four sub-projects developed as part of the proof-of-concept model. Details of these sub-projects are presented in section 7.2.

The spatial and non-spatial data inputs feeding into the model framework are discussed in section 7.3 and a process for linking the indicators to the spatial road segments from which they are calculated is proposed in section 7.4 for both PT and non-PT data.

The data schema and specific process of converting raw data to each indicator is then discussed in section 7.5 with the resultant spatial database framework presented diagrammatically in section 7.6.

Figure 7.1 Overview of the database framework



7.2 Proof-of-concept sub-projects

Four proof-of-concept sub-projects were identified to test the digital data from both Bluetooth and GPS sources, against a range of applications, including rural and urban environments, SH and local roads, PT and private motor vehicle modes. A summary of the sub-projects and indicators derived from each are provided in table 7.1.

Table 7.1 Summary of proof-of-concept datasets and indicators to be tested

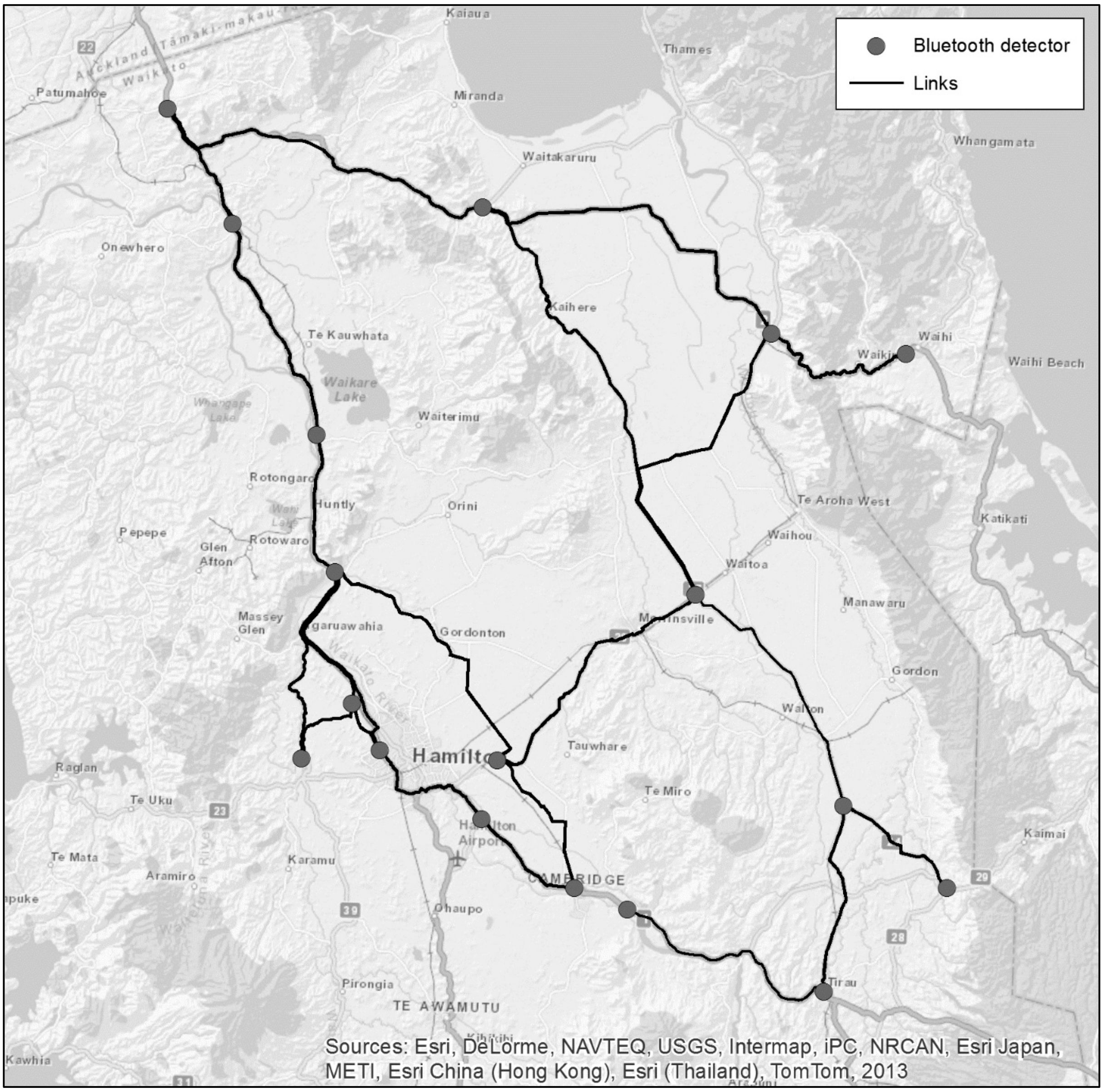
<table>
<tr><th colspan="2">Indicator</th><th>Waikato SH network (BT</th><th>Auckland local roads (BT)</th><th>Wellington SH network (GPS)</th><th>Auckland PT (GPS)</th></tr>
<tr><td>NP1.1</td><td>Average travel time – private vehicle</td><td>Y</td><td>Y</td><td>Y</td><td></td></tr>
<tr><td>NP1.2</td><td>Average speed – private vehicle</td><td>Y</td><td>Y</td><td>Y</td><td></td></tr>
<tr><td>NP1.3</td><td>Average travel time – PT</td><td></td><td></td><td></td><td>Y</td></tr>
<tr><td>NP1.4</td><td>Average speed – PT</td><td></td><td></td><td></td><td>Y</td></tr>
<tr><td>NP2.1</td><td>Minutes delay per km – private vehicle</td><td>Y</td><td>Y</td><td>Y</td><td></td></tr>
<tr><td>NP2.2</td><td>Minutes delay per km – PT</td><td></td><td></td><td></td><td>Y</td></tr>
<tr><td>NP3.1</td><td>Standard deviation speed</td><td></td><td></td><td>Y</td><td></td></tr>
<tr><td>NP3.2</td><td>15th percentile speed</td><td></td><td></td><td>Y</td><td></td></tr>
<tr><td>NP3.3</td><td>85th percentile speed</td><td></td><td></td><td>Y</td><td></td></tr>
<tr><td>NP4</td><td>Variation from speed limit</td><td>Y</td><td>Y</td><td>Y</td><td></td></tr>
<tr><td>NP5</td><td>Estimated hourly volume</td><td>Y</td><td>Y</td><td></td><td></td></tr>
<tr><td>HE1.1</td><td>Rate of emissions – CO</td><td rowspan="4">Y</td><td rowspan="4">Y</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>HE1.2</td><td>Rate of emissions – N_2O</td></tr>
<tr><td>HE1.3</td><td>Rate of emissions – PM_{10}</td></tr>
<tr><td>HE1.4</td><td>Rate of emissions – VOC</td></tr>
<tr><td>HE2</td><td>CO_2 emissions</td><td>Y</td><td>Y</td><td></td><td></td></tr>
<tr><td>S1</td><td>VKT by star rating</td><td>Y</td><td></td><td></td><td></td></tr>
<tr><td>A1</td><td>Vehicle km travelled (VKT)</td><td>Y</td><td>Y</td><td></td><td></td></tr>
<tr><td>A2</td><td>Total freight tonne km</td><td></td><td></td><td>Y</td><td></td></tr>
<tr><td>C1.1</td><td>Cost per VKT</td><td rowspan="2">Y</td><td rowspan="2">Y</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>C1.2</td><td>Total cost of travel</td></tr>
<tr><td>C2.1</td><td>Cost per freight tonne km</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">Y</td><td rowspan="2"></td></tr>
<tr><td>C2.2</td><td>Total cost of freight travel</td></tr>
</table>

7.2.1 Waikato State Highway (Bluetooth)

Bluetooth data for the Waikato region was used to generate nine indicators across the SH network. This network includes a range of motorway, rural and urban road environments. The sample data covers 36 road links across 19 Bluetooth monitoring points. Compared with the Auckland Bluetooth project (see section 7.2.2), this dataset contains relatively long monitored road segments with routes ranging between 5km and 50km.

The extent of the SH network monitored, including the location of Bluetooth detectors, is displayed in figure 7.2.

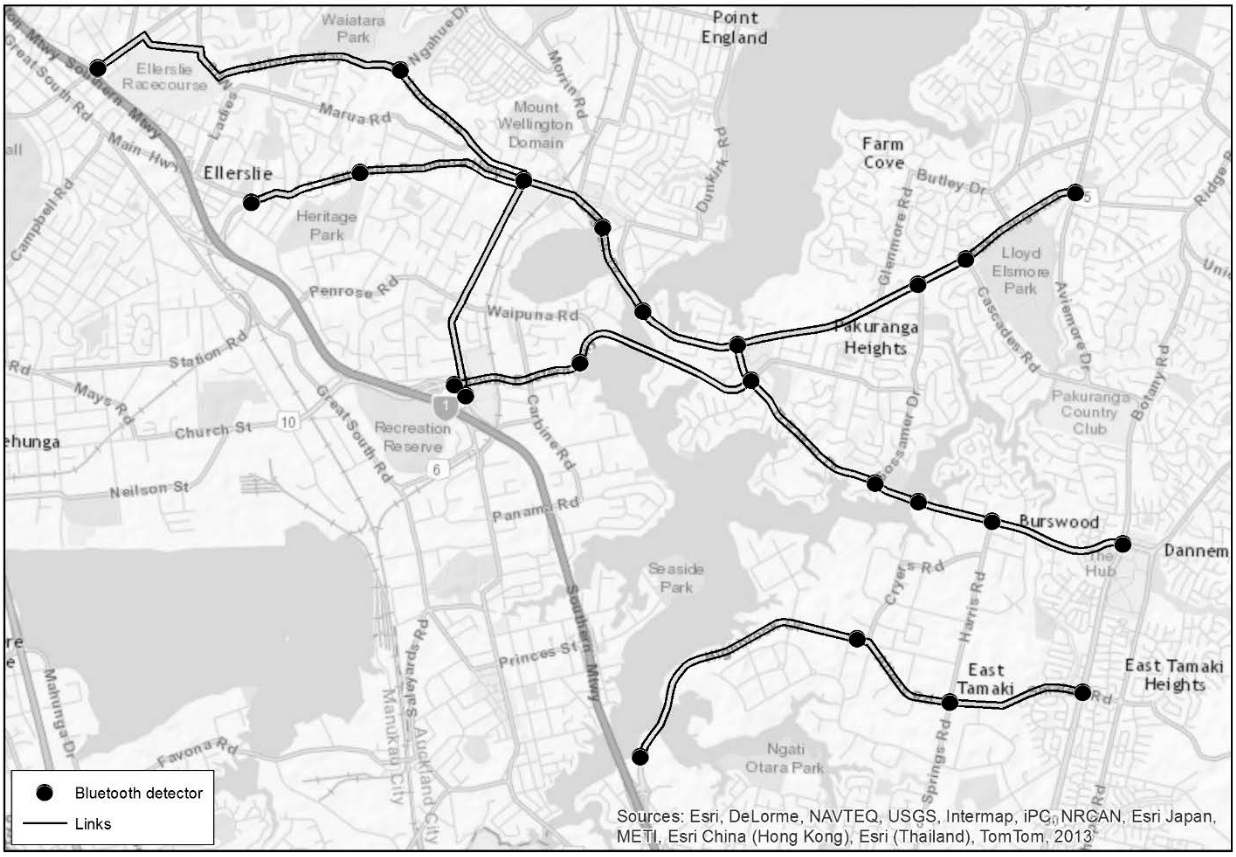
Figure 7.2 Waikato State Highway sub-project: routes monitored and detector locations



7.2.2 Auckland local road network (Bluetooth)

Bluetooth data was also used to generate nine indicators across the urban road network of the eastern suburbs of Auckland. The data provided covers 35 routes across 26 Bluetooth detectors, with route segments ranging in length from 0.35 to 4.5km. Figure 7.3 shows the spatial extent of the monitoring sample data provided. Although this is not a SH application, the dataset is included to explore the potential of Bluetooth data sources in congested urban environments.

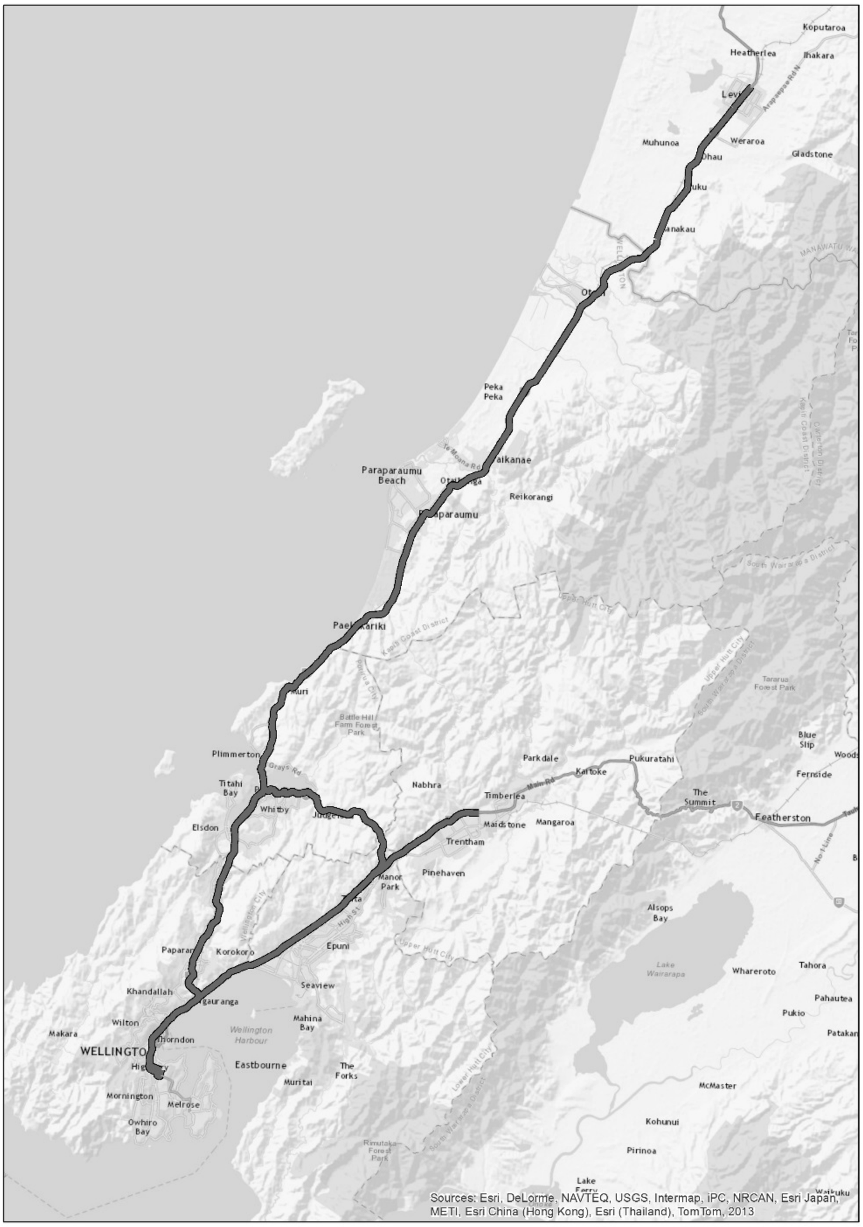
Figure 7.3 Auckland local network: routes monitored and detector locations



7.2.3 Wellington state highways (GPS)

Location and traversal time data from a GPS dataset was used to generate indicators across the Wellington SH network (figure 7.4). The sample GPS data provided covers 168 road segments of SH1, SH2 and SH58 in the Wellington region (refer figure 7.4), with speed data provided separately for the following EEM vehicle classes: light (LCV), medium (MCV) and heavy (HCV1, HCV2) commercial vehicles.

Figure 7.4 Wellington State Highway sub-project: road network monitored



7.2.4 GPS – Auckland Public Transport

Auckland Transport uses GPS to track the performance of bus services across the city (Auckland Transport 2013b). The sample GPS data provided by Auckland Transport reports against routes and stops, providing information on the arrival and departure times of buses on different routes at different times of the day. This data covers 138 bus routes connecting 3,961 individual stops over a 24-hour period.

As the Auckland PT GPS data was collected for the purpose of monitoring route performance, rather than the performance of PT road corridor segments, analysis of this data involved some additional steps. This is discussed in more detail in section 7.4.2.

7.3 Digital data inputs

Two types of information are required from each data supplier in order to enable indicators to be spatially mapped over road centreline segments.

First, to define the segments between monitoring points, a set of start and end point locations and/or spatial route information (eg shapefile format) must be provided. Each data supplier has made this available in different formats, including KML, ESRI shapefile or tables, eg comma-separated values (CSV) format, with latitude and longitude coordinates of segment start and end points.

Second, the data provided also includes table (or field) information that contains the raw recorded data from which indicators can be generated. The data suppliers have also provided this in table (CSV) format, with each table including date and time stamps, traversal time (or average speed) and count data.

On an ongoing basis, digital travel-time data may continue to be provided in CSV or alternative table format; however, the database framework developed in this chapter is sufficiently flexible to adapt to alternative spatial data sources in the future, including live feeds and web services. Spatial interoperability tools can also be used to provide a platform for interpreting alternative sources of data such as these.

7.4 Generation of centreline segments

To enable indicators to be spatially represented on a map, they must be referenced against the segment or 'link' of road from which they were calculated. The same CAS centreline road network is used for all the sub-projects, therefore the sample data must be mapped against this dataset.

The process of extracting road centreline links from the centreline dataset involves a mix of automated analysis and manual editing, depending on the type of data provided and the scale of the sub-project. The outputs of the road centreline link generation are a standardised line feature dataset for each sub-project. The attributes of the road centreline link features match the schema identified in the sub-project, noting that not all fields may be required for some sub-projects, for example average star rating is only calculated for SH road centreline links.

For each centreline link, a unique 'link_ID' primary key field is generated which links the centreline link geometry to the table data collected for that link. The format of this field varies depending on the initial data source, for example it could be a combination of the start_ID and end_ID point locations provided. Whatever the format, the link_ID enables directionality (the direction of traffic flow relative to the geometry) to be displayed.

Generating the road centreline links for each dataset only needs to occur once. While the data assigned to each link changes over time, the physical geometry of these links does not. If there is any subsequent change to the road centreline or monitoring network, this can be edited into the road centreline link dataset as required. This can be included as part of a regular 'maintenance' update to the model as the data inputs (including network centreline) and needs evolve.

There is a risk with establishing unique link IDs that if the underlying road network changes or if the input digital data waypoints change, considerable effort will be required to update the network and the underlying data attributes. This issue must be managed carefully and it is plausible that models can be developed to first, identify network and dataset changes and second alter the centreline and update link IDs accordingly.

7.4.1 Non-PT road centreline link mapping

The process to extract the road centreline depends on each project and the length of links required. Once the road centreline link has been created, a unique link_ID primary key is created and the attributes associated with that length of underlying road centreline are extracted. This includes attributes for hierarchy, urban versus rural flow (AADT) and posted speed limit. For some of the longer road centrelines where the road classification changes along their length, it is necessary to extract proportional (weighted) attributes.

Gradient and average RPS rating are also extracted for each road centreline link, where relevant. Gradient is determined by analysing the difference in elevation at 100m intervals along the link using the GIS spatial analysis. The average gradient is then calculated and checked to ensure they are realistic and relevant.

The average star (KiwiRAP) ratings of SH centrelines is determined by joining the 100m KAT data points to the SH centreline links. The average value across all the KAT points is then calculated.

For each road centreline link, weighted average AADT is calculated from the available AADT traffic count data within the CAS road centreline. The AADT is stored as a ‘flow’ attribute within the road centreline for each 100m length of SH and originates from RAMM data.

The final output of this data processing step is a road centreline feature class with attribute values assigned as per table 7.2.

Table 7.2 Non-PT road centreline link schema

Attribute	Data type	Comment
link_ID	Text	A unique primary key for the link
urban_or_rural	Text	
hierarchy	Text	This attribute will be either ‘arterial/strategic’ or ‘other’
length	Floating-point	
posted_speed_limit	Integer	This value will be weighted by length, where required
gradient	Floating-point	
weighted_AADT	Integer	The average, weighted AADT for the link
average_star_rating	Floating-point	Values only for SH centrelines

7.4.2 PT road centreline link mapping

The methodology for generating both the PT road centreline links and travel-time data has been discussed in detail in section 6.1.2. Unlike the non-PT centreline dataset, no other variables (eg gradient, AADT and speed limit) are required, therefore there are no additional processing steps required to extract this data. The general format for PT road centreline link data is presented in table 7.3.

Table 7.3 PT road centreline link schema

Attribute	Data Type	Comment
link_ID	Text	The unique link_id combines the start and end bus stop number (eg “3076_3001”)
start_stop_number	Integer	The stop location that represents the start of the centreline link
end_stop_number	Integer	The stop location that represents the end of the centreline link
Length	Floating-point	Automatically generated from the feature geometry

7.5 Data processing

Each data supplier delivered sample data in a table format that could be used to generate indicators over different time periods. Between providers the layout or 'schema' of this data varies significantly and needs to be converted to a standard table schema. The output tables from the data processing step can then be joined using a unique link_ID to the centreline geometry to generate the indicators identified using a series of table calculations.

The process of converting raw data to indicators is discussed in the following sections.

7.5.1 Non-PT data processing

For non-PT projects, the sample data tables provided are relatively small and easy to work with. Hence for the proof-of-concept stage of this research, the conversion of raw table data into the standard table schema has been done manually using Excel or ArcGIS table tools.

The standard output data table schema for non-PT data is set out in table 7.4. As recommended in chapter 6, data is aggregated to 60-minute intervals by day of the week. Further aggregation of the data may occur before the indicators are generated (see section 7.6).

Table 7.4 Digital data table schema (non-PT)

Attribute	Data Type	Comment
link_ID	Text	A unique primary key
day_of_week	Integer	A number that represents the day of week (eg 1 to 7)
hour_interval	Integer	A number that represents the hourly interval (eg 1 to 24)
ave_traversal_time OR ave_speed	Floating-point	This field will vary depending on whether the supplier provided raw speed or travel-time data. This is aggregated to a 60-minute period.
sample_count	Integer	The number of matched samples
standard_dev	Floating-point	Variance measures as supplied by the data supplier (not all datasets will have these attributes)
percentile_15		
percentile_85		
HGV_count	Integer	Sum of LCV, MCV, HCV I and HCV II vehicles (if available)

7.5.2 PT data processing

For the PT GPS sub-project, the difference between the bus leaving the first stop and arriving at the second stop is calculated as the traversal time for each road centreline link. An 'intermediate' output table for each bus service is generated as set out in table 7.5.

Table 7.5 Intermediate table schema for bus services

Attribute	Data type	Comment
route_UID	Integer	The unique route identifier
service_start_time	Date/time	The time the service initially started
date	Date/time	The date on which the service occurred.
link_ID	Text	The unique primary key based on the start and end stop IDs
start_stop_number	Integer	
end_stop_number	Integer	
start_stop_sighting_time_exit	Date/time	The time the bus was recorded leaving the start stop
end_stop_sighting_time_entry	Date/time	The time the bus was recorded arriving at the end stop
traversal_time	Floating point	The different between the exit and entry times

All the intermediate table outputs for each route and service are combined and aggregated by link_ID and hour interval as set out in table 7.6.

Table 7.6 Output digital data table schema for bus services

Attribute	Data type	Comment
link_ID	Text	A unique primary key based on the start and end stop IDs
day_of_week	Integer	A number that represents the day of week (eg 1 to 7)
hour_interval	Integer	A number that represents the hourly interval (eg 1 to 24).
ave_traversal_time	Floating-point	The average traversal time for all services that travel over the centreline link.
service_count	Integer	The number of services that travel over the centreline link

Aggregation of service data by link_ID enables the average traversal times of multiple services crossing the same road centreline link to be calculated. The additional 'service_count' field provides a measure of how many services cross each centreline link in a single hourly period.

7.6 Generating the indicators

To generate the set of indicators identified in chapter 4, the output data tables and centreline link are joined so that attributes from both the geometry and table data sources can be combined using the unique link_ID field.

Some indicators require intermediate indicators to be generated first. Tables 7.7 and 7.8 set out the calculations required to generate the intermediate and output indicators respectively. The input data fields in these tables refer to the table schemas previously identified, and do not include calculations where a change of unit is required, for example, from seconds to minutes. These calculations are implied.

All of the intermediate indicators in table 7.7 are intended to be calculated for each route across the entire vehicle fleet for the Bluetooth sub-projects. HCV-related indicators are only calculated where this data has been provided by the supplier (the Wellington sub-project).

Table 7.7 Intermediate indicator calculations

Intermediate indicator	Input data fields			Indicator calculation	Units	Comments
	Links (geometry)	Digital data (table)	Other inputs			
Total_hours_ travelled	n/a	[ave_traversal_time]	[VKT_calculated]	[ave_traversal_time] * [VKT_calculated]	Hours	VKT_calculated is generated by indicator NP4. This indicator is required for calculating 'C1 - total cost of travel'
Base_vehicle_operating_cost	[length] [gradient] [hierarchy] [urban_or_rural]	[ave_traversal_time]	[ave_speed] EEM look-up tables A5.7-A5.10	Extract value from the relevant EEM look-up table	cents/VKT	This indicator is required to calculate total cost of travel and CO_2 emissions
Base_travel_time_cost	[hierarchy] [urban_or_rural]	n/a	EEM look-up table A4.1	Extract value from the relevant EEM look-up table	$/hour	This indicator is required to calculate total cost of travel
Total_HCV		[HCV_count]	[freight_sample_rate]	[HCV_count]* [freight_sample_rate]	HCV vehicles	These indicators are required to calculate freight cost and activity indicators
HGV_VKT	[length]		[total_HCV]	[Total_HCV]*[length]	HCV VKT	

Table 7.8 Output indicator calculations

Indicator		Input data fields			Indicator calculation	Output field(s)	Units
		Links (geometry)	Digital data (table)	Other inputs			
NP1.1 NP1.3	Average travel time	[length]	[ave_speed]	n/a	[length]/ [ave_speed]	[ave_traversal_time]	Seconds
NP1.2 NP1.4	Average speed	[length]	[ave_traversal_time]	n/a	[length]/ [ave_traversal_time]	[ave_speed]	Km/h
NP2.1 NP2.2	Minutes delay per km	[length]	[ave_traversal_time]	[min_ave_traversal_time]	([ave_traversal_time] - [min_ave_traversal_time]) / [length]	mins_delay_km	Mins/km
NP4	Variation from posted speed	[posted_speed_limit][length]	[ave_traversal_time]	n/a	[posted_speed_limit] - ([ave_speed])	variation_posted_speed	Km/h

Indicator		**Input data fields**			**Indicator calculation**	**Output field(s)**	**Units**
		Links (geometry)	**Digital data (table)**	**Other inputs**			
NP5	Estimated hourly volume	n/a	[sample_count]	[expansion_factor]	[sample_count] * [expansion_factor]	est_hour_volume	vehicles
HE1.1 to 1.4	Emissions	[length]	[ave_traversal_time]	EEM emission factors 'A','B','C' for each emission type - table A9.3	Emissions formula: ((A*[ave_speed][ave_speed] + B*[ave_speed] + C) * [VKT_calculated])/[length])	CO_emission	grams/km
						Nox_emission	grams/km
				[ave_speed]		PM10_emission	grams/km
				[VKT_calculated]		VOC_emission	grams/km
HE2	CO_2 emission	n/a	n/a	[base_vehicle_operating_cost]	[base_vehicle_operating_cost] *4%	CO2_emission	Tonnes
A1	Vehicle kilometres travelled (VKT)	[length]	n/a	[vehicles_total]	[Vehicles_total] * [length]	VKT_calculated	Vehicle-km
A2	Total freight tonne km	[length]		[HCV_VKT]	[HCV_VKT] *[ave_freight_load]	freight_tonnekm	Tonnes km
C1.1	Cost per kilometre travelled	[length]		[travel_cost] (see below)	[travel_cost]/[length]	cost_per_km	$/km
C1.2	Total cost of travel	n/a	n/a	[base_vehicle operating cost] [base_travel_time_cost] [VKT_calculated] [total_hours_travelled]	([base_vehicle_operating_cost] * [VKT_calculated]) /100 + [base_travel_time_cost] * [total_hours_travelled]	total_cost	$
C2.1	Cost per freight tonne km			[freight_tonnekm_cost] (see below)	[freight_tonnekm_cost]/ [length]	cost_per_freight_km	$/km
C2.2	Total cost of freight travel	n/a	[freight_tonnekm]	[base_vehicle_operating_cost] [base_travel_time_cost] [VKT_calculated] [total_hours_travelled]	([base_vehicle_operating_cost] * [VKT_calculated]) /100 + [base_travel_time_cost] * [total_hours_travelled] / [freight_tonne_km]	total_freight_cost	$

7.7 Spatial database framework

For the purposes of the proof-of-concept model, spatial and non-spatial data was stored and processed in a series of ArcGIS file geodatabases as either tables or feature classes. Figure 7.5 (for the three non-PT sub-projects) and figure 7.6 (for the Auckland PT GPS sub-project) set out the diagrammatic framework for how spatial and non-spatial data is stored. These diagrams are conceptual and generalise the data flow and analysis steps that apply to each sub-project's dataset. These diagrams also demonstrate the data schema that apply to each dataset as it is processed, including intermediate datasets that are generated. A number of additional spatial and non-spatial data sources have also been identified.

Considering the potential expansion of this research project beyond the sample datasets provided, programming scripts or ETL (extract, transform, load) software could be applied to automate the conversion of raw data into the standard format and the generation of indicators. The type of automated processing required will depend on the scale of the data provided in terms of both the spatial scale (for example the entire country versus a regional network), and temporal scale (for example a single month or year of data versus a live data feed).

Figure 7.5 Non-PT sub-projects data conceptual database framework

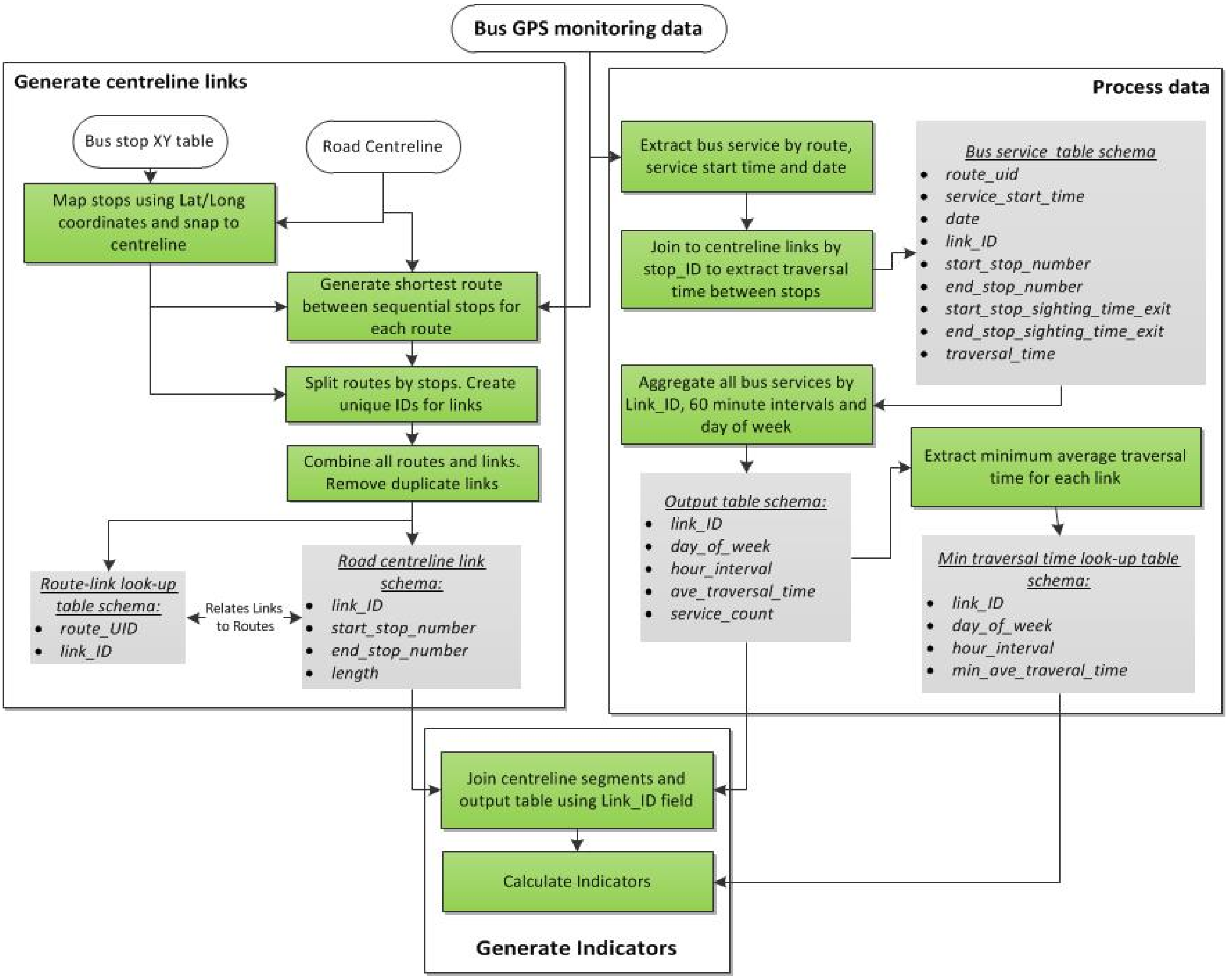
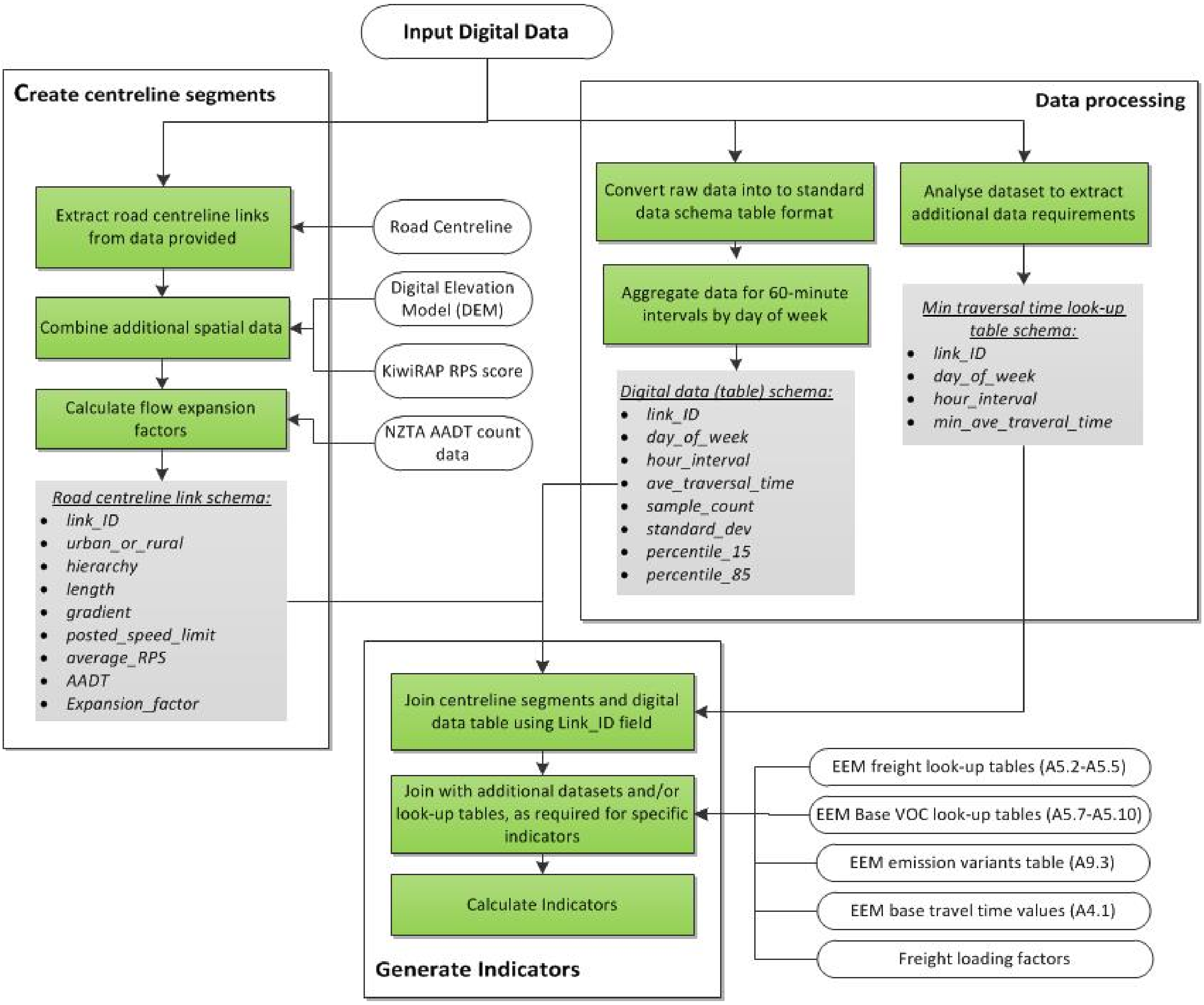


Figure 7.6 PT sub-project data conceptual database framework



8 Proof-of-concept model delivery

This chapter describes the implementation of the proof-of-concept model presented in chapter 7. Each sub-project dataset and the integration with other spatial and non-spatial data inputs are discussed in section 8.1. A GIS web viewer has been developed to display the outputs of the model. This website has been made available to the Transport Agency and is user name and password controlled. A user guide for this viewer is included as appendix C.

In section 8.2 the range of model validation steps undertaken in the model development process is documented to demonstrate the robust process by which the outputs are validated and authenticated.

8.1 Proof-of-concept model implementation

8.1.1 Waikato State Highway network (Bluetooth)

The indicators derived from the Waikato SH Bluetooth system were generated from four weeks of data (2 to 27 September) aggregated to a single 24-hour period. Data was not available for all links for this time period due to the underlying dataset being incomplete. For example, no data was available for SH1 between Cambridge and Hickey Road, and in one direction along SH27 from SH26 to Matamata. For some hour periods, no Bluetooth matches were recorded on low volume links – for example link ‘3683_3713’ (Limmer Road and Koura Drive from SH39 to Hamilton) had poor Bluetooth sample rates during off-peak periods.

Indicator S1 (road assessment rating – VKT by star rating) was modelled exclusively for this sub-project, due to the availability of estimated hourly counts (indicator NP5) and the rural nature of the network.

8.1.2 Auckland local road network (Bluetooth)

The indicators derived from the Auckland local road Bluetooth network were generated from one week of data provided by the Bluetooth data supplier (the first week of February 2013). One of these days was a public holiday (Waitangi Day) and was subsequently removed from the data aggregation. The data was only available in half or quarter hour intervals during the peak (6am to 9am and 4pm to 6:30pm) and off-peak (9:30am to 10am and 1:30pm to 2pm) periods.

As a result, data for time periods prior to 6:30am or after 6:30pm do not appear in the web viewer; however, it is noted that 24-hour coverage of data is available from the data supplier upon request. The implications are that the full contrasts between indicator outputs for congested and uncongested times of day are not evident and the model will most likely under-predict the minutes of delay per km (NP2.1) indicator.

8.1.3 Wellington region SH network (GPS)

A data sample from the GPS data set was supplied in shape file GIS format, with 24 hours of speed data (mean, median, standard deviation, 15th and 85th percentile) provided for each RUC vehicle class.

This sub-project was the only one in which reliability indicators NP3.1-NP3.3 (standard deviation, 15th and 85th percentiles) and freight indicators (A2 – total freight tonne km and C2 – cost per freight tonne km) were calculated and mapped in the proof-of-concept model.

The data was supplied with vehicles categorised using the latest (effective as of 1 July 2013) RUC vehicle class definitions specified in NZ Transport Agency (2013d). It was noted that the RUC classifications did not match those defined in the EEM. Therefore the RUC-based MCV, HCV I and HCV II vehicle counts and speeds were aggregated into a single 'heavy vehicle' category. By aggregating vehicle classes, the model also benefited from an increased sample size. If the RUC classes were more clearly attributable to the EEM vehicle classes, these could be disaggregated accordingly in future reporting.

Aggregated 'heavy vehicle' counts (using weighted averages of outputs by vehicle class) were compared against the known HCV fleet composition from the nearest Transport Agency telemetry count site to each road segment (consistent with the methodology described in section 6.1.7.2) to generate estimated HCV hourly counts, from which the indicators C2 and A2 could be calculated.

As the underlying vehicle classes (MCV, HCV-I and HCV-II) were aggregated into a general 'heavy vehicle' class a typical fleet composition was calculated based on an analysis of the Wellington region Transport Agency telemetry count data within the data capture area (site IDs 00210979, 00220979, 01N01036, 01N11068, 01N21068, 05800009, 01N00988, 00210965 and 00220965).

The analysis established that approximately 56% of heavy vehicles were MCV, 17% HCV-I and 27% HCV-II EEM classes. Therefore the travel-time and road user costs calculated from the EEM were a weighted average of the EEM class values, as they assume this breakdown is the 'typical' fleet composition for the study area.

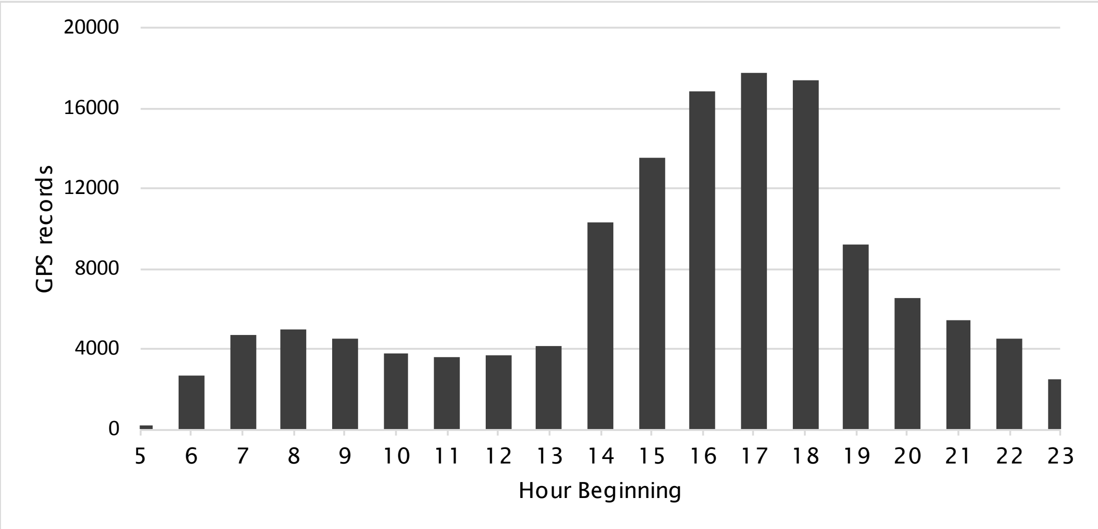
The resultant cost per freight tonne km varied between $0.22 and $0.86, assuming an average freight load of 7.07 net tonnes per HCV vehicle taken from the MoT's (2012b) vehicle fleet statistics. These figures are comparable with typical freight cost measures reported in Pearson (2007) and MoT (2010).

8.1.4 Auckland public transport network (GPS)

From the 24-hour data provided, a total of 5,942 individual links (segments of road between bus stops) were mapped, providing near-complete coverage of all the Auckland region's bus corridors. The two indicators for this project (travel time and minutes delay per km) were successfully generated.

There was a discrepancy between data sources (bus stop point locations and GPS table data) where bus stop IDs were referenced on one source, but not the other. This meant that some links could not be mapped as either the bus stop or GPS data was missing for that location. Similarly, GPS data was not available for all links and all times of the day, for example services on Waiheke Island. Also, the data supplied included less data for the period prior to 2pm compared with the rest of the day, as indicated in figure 8.1.

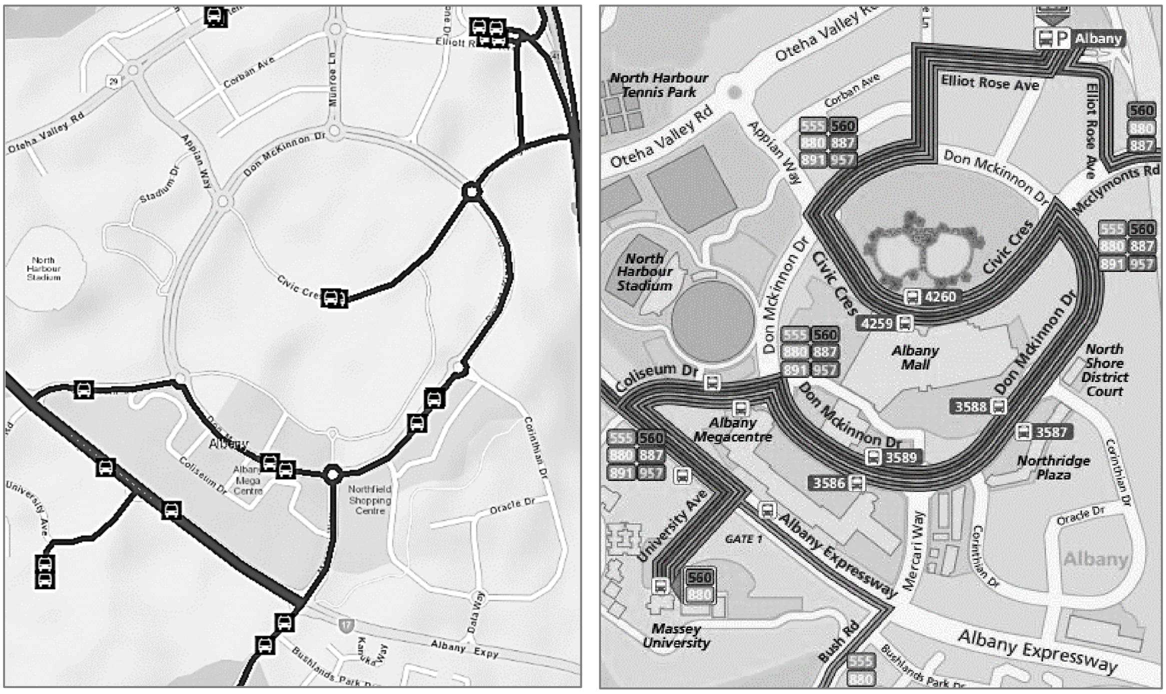
Figure 8.1 GPS PT sub-project: GPS records by time of day



Individual road segments were generated from the CAS centreline by finding the shortest route between coincident stops along a bus route using network analysis, assuming that buses always travel the shortest route between adjacent stops. While this is a correct assumption for most routes, there were some exceptions as shown in figure 8.2. This figure demonstrates how the methodology assumed a route via Mecari Way, and a U-turn in Civic Crescent.

Figure 8.2 Example of errors caused by shortest path route analysis: Albany Mall

Bus routes generated from shortest path analysis *Bus routes from timetable (AT, 2012)*

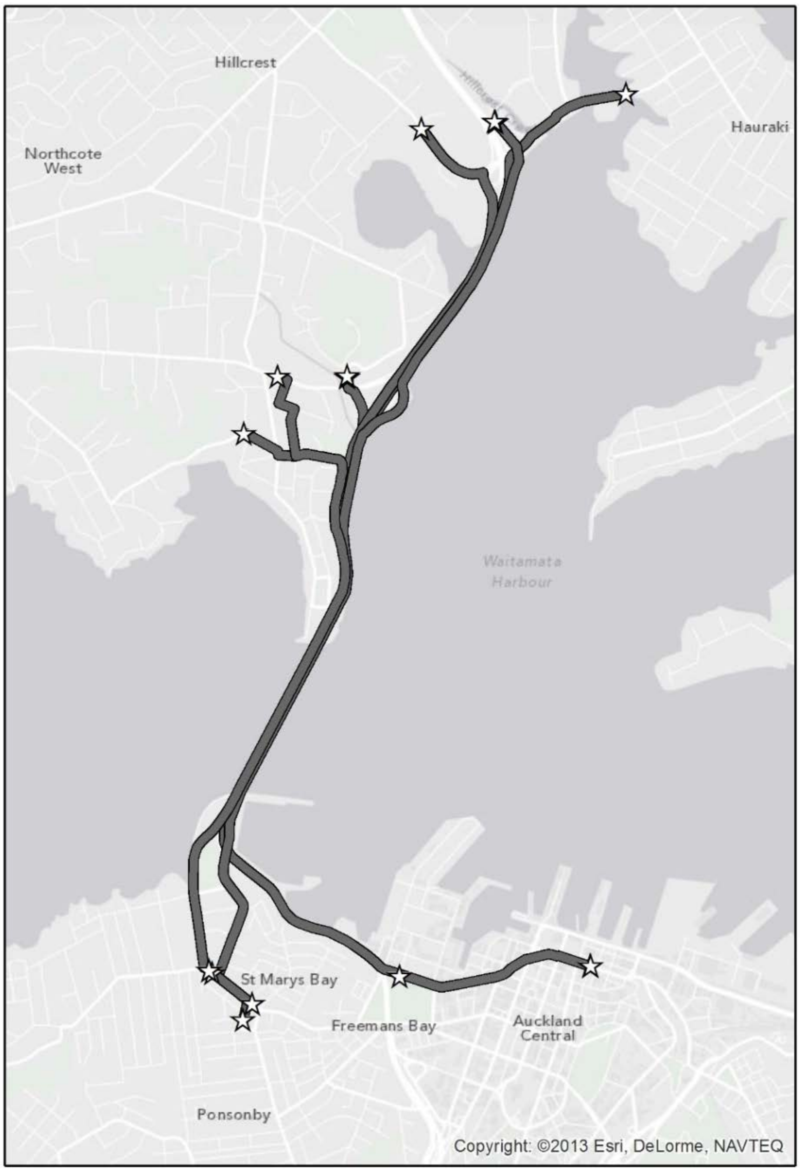


Errors with routing also occurred when buses travelled along accessways not mapped in the CAS centreline, eg through large shopping centres or institutions such as hospitals and tertiary education campuses. Additional routing errors occurred where the shortest path involved traversing the wrong side of a motorway or one-way street. This was inevitable as the CAS centreline did not have a directionality attribute that restricted where vehicles could turn or travel in the network analysis. Due to the high number of links generated (over 6,000) it was not possible to manually check and correct all the inaccurately generated links, especially as a GIS layer of bus routes was not provided by the supplier. An alternative centreline identifying both directionality and private access ways should therefore be considered for future analyses.

Data validation revealed that in approximately 0.05% of the trips between stops, the data indicated that a bus had arrived at the second stop before leaving the first, resulting in negative travel times. Careful checking was undertaken to remove negative or errant travel-time values.

Many links in the PT network overlapped, for example where different bus routes use the same corridors but start or end at different stops. Figure 8.3 provides an example of this, showing all the different links that cross the Auckland Harbour Bridge. The inability to aggregate to single corridors such as this means it is difficult to provide a single metric to represent the speed of buses travelling along motorways and major arterials. Alternative methods of analysis for aggregating indicators along key corridors, taking into account overlapping links, could be explored to take account of this overlap.

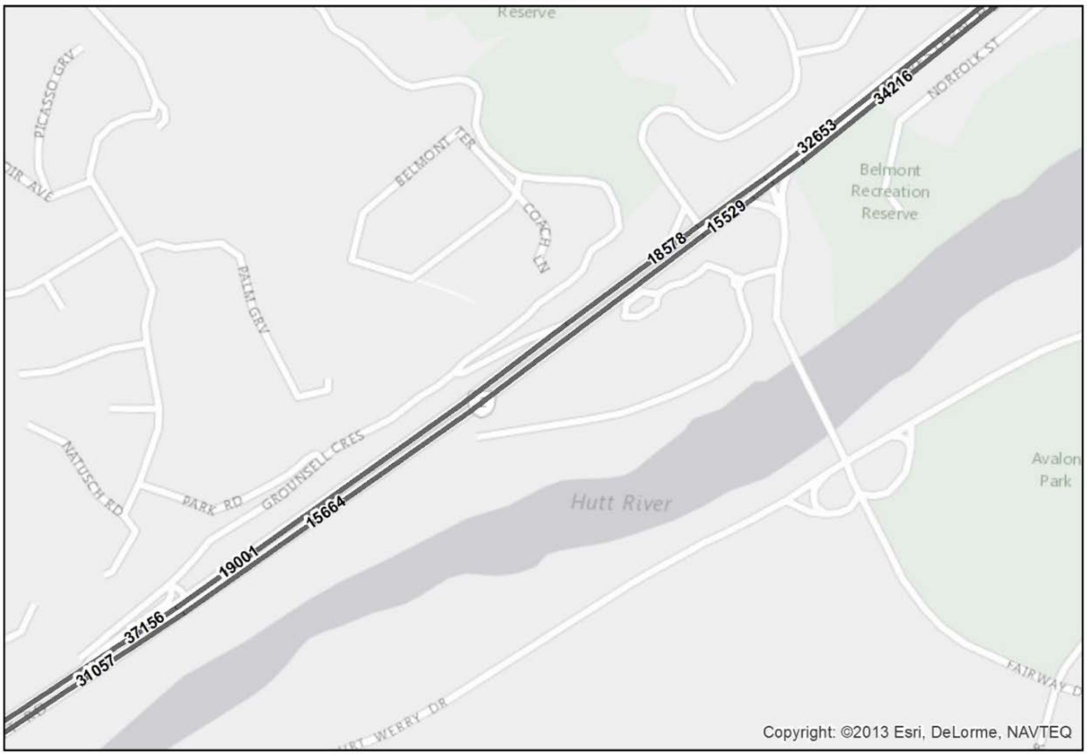
Figure 8.3 Example of how different bus routes use the same corridor (Auckland Harbour Bridge)



8.1.5 Other data inputs

The Transport Agency's CAS centreline was used throughout the analysis as it provided both AADT and speed limit data, not currently available on other GIS centrelines, and covered both the SH and local road networks nationwide. The AADT and speed limit values were occasionally incorrect, either due to the age of the data (for non-SH roads only) or where AADT counts had been incorrectly modelled across divided carriageways. Figure 8.4 demonstrates how this occurs. The AADT for a single direction for this part of SH2 in Wellington should be between 15,000 to 20,000, indicating that some single direction sections were incorrectly assigned 'both' direction AADT counts to each centreline without any division by direction (31,000 to 37,000 AADT values).

Figure 8.4 Example of incorrect AADT values on CAS centreline (SH2 Wellington)



Any unusual values were manually corrected by comparing segments of centreline against known AADT counts and speed limit data, including Transport Agency count sites and KiwiRAP analysis tool (KAT) data.

A digital elevation model (DEM) was used to calculate grade for every road link in the model, excluding the PT sub-project. The DEM used for this analysis had a relatively fine resolution of 15m; however, exceptionally high grades (up to 25%) were generated in areas with complex topography, for example over bridges, along gorges or in areas where there had been substantial cut or fill. All grades calculated over 10% were manually checked, and where required, a reasonable grade for these sections was estimated, taking into account the terrain and the surrounding centreline grade values.

8.1.6 GIS web viewer

The proof-of-concept model is delivered as a GIS web viewer, created in ArcGIS Viewer for Flex, and displays all 23 of the indicators generated and listed in table 7.1. In addition to the visual display, indicator values for each link can be viewed in pop-ups by clicking on each network link. At present, the visual display and link pop-ups only display data for the hour shown; however, they can also be designed to display daily results or provide other aggregated statistics designed to meet the user requirements.

Each model layer is attributed to an eight-point colour scale within the model to provide a meaningful comparison across the study area and over different time periods. Negative values may be encountered for indicators NP2 (minutes delay per km) and NP4 (variation from posted speed limit). This implies that for the particular link and time-period selected, vehicles are travelling at speeds higher than the speed limit. This is more likely to occur along motorways or expressways during off-peak periods.

Example screenshots of the web viewer are provided on the following pages and represent the following:

- Figure 8.5 demonstrates estimated hourly volumes generated from a Bluetooth data source on a portion of the Auckland local road network. For the hour shown (5pm) the estimated hourly volume values demonstrate peak flow traffic radiating away from the Auckland central business district. Fourteen indicators can be displayed for this sub-project.
- Figure 8.6 displays the Waikato SH Bluetooth monitoring sub-project. This example shows average speeds across the network monitored for a single hourly period (8am). An example of a data pop-up is also provided, demonstrating how the underlying data can be queried by the user. Fifteen indicators can be viewed for this sub-project.
- Figure 8.7 demonstrates the cost per freight tonne km, generated from GPS data for the Wellington regional SH network. The web viewer clearly displays changes in freight costs across the network for the single hourly period viewed (8am). Nine indicators can be viewed for this sub-project, including two freight-related measures.
- Figure 8.8 displays the travel reliability indicator minutes delay per km for PT which has been calculated using GPS data. A peak-hour interval (5pm) was chosen to demonstrate high levels of delay across a number of Auckland's arterial routes. Average travel-time data can also be viewed for this sub-project.

Figure 8.5 Estimated hourly volume: Auckland local road network

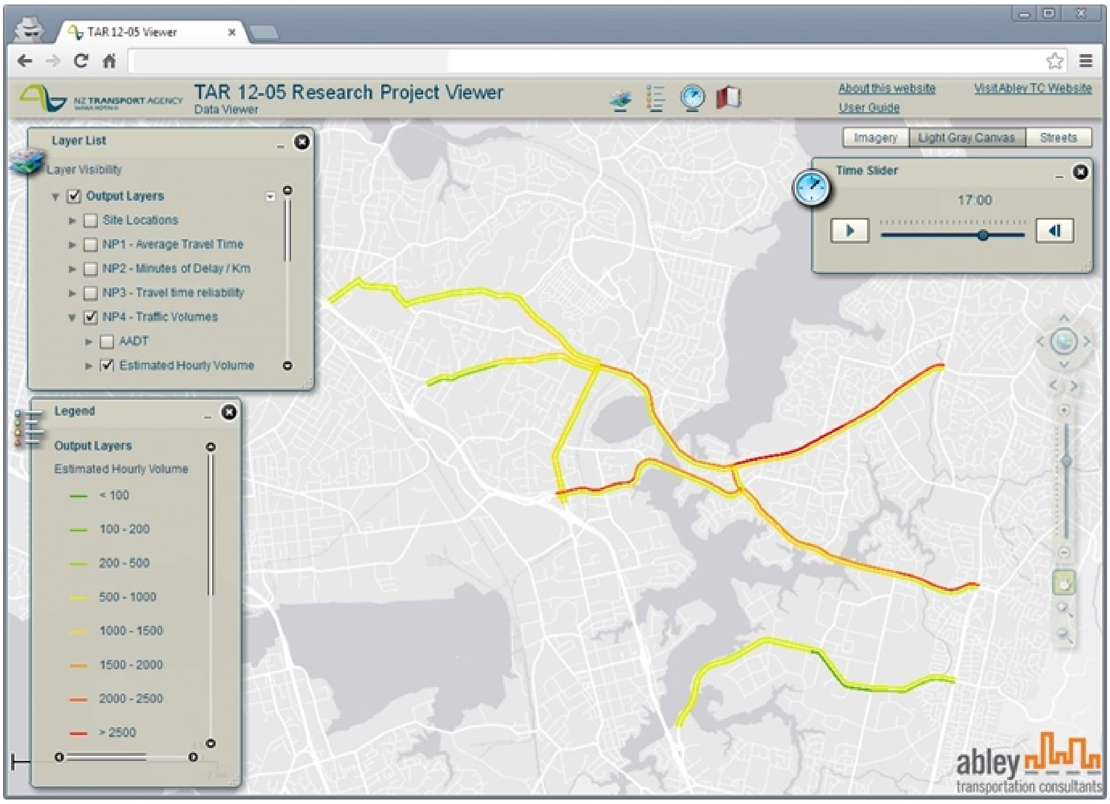


Figure 8.6 Average speed and pop-up display example: Waikato State Highway sub-project

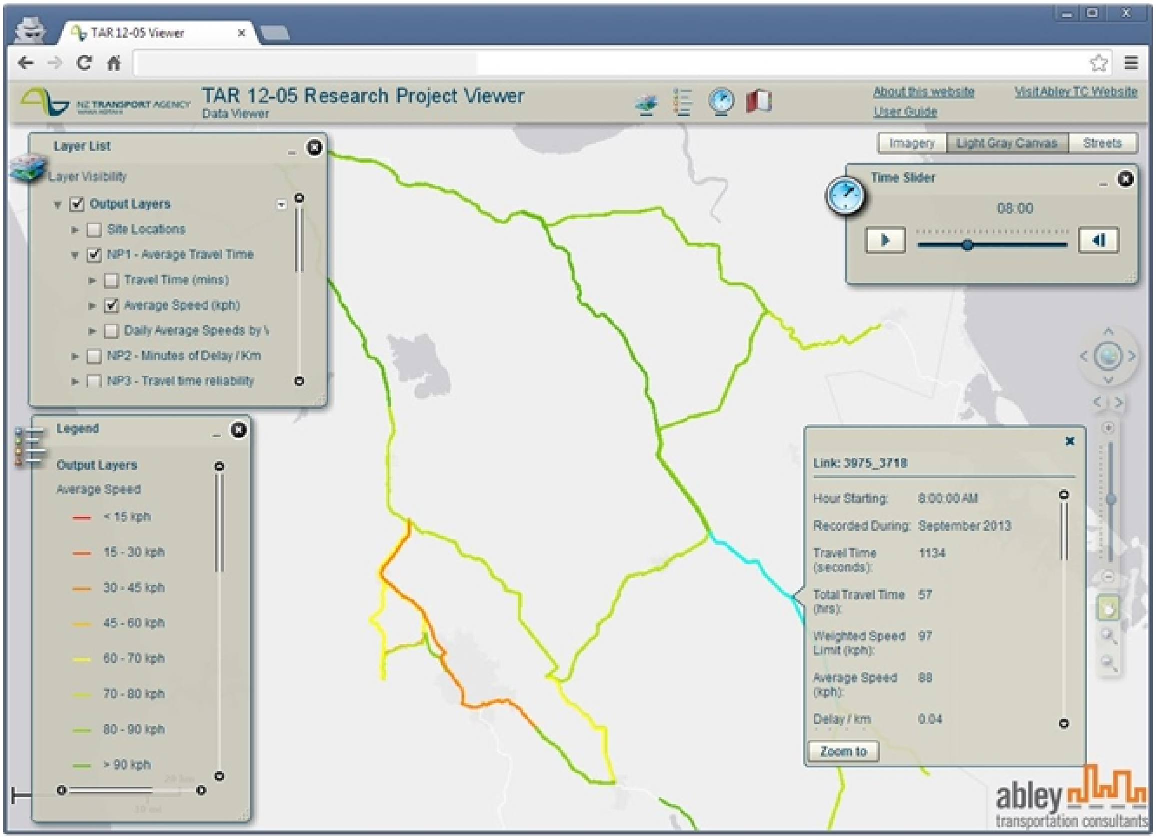


Figure 8.7 Cost per freight tonne km example: Wellington State Highway

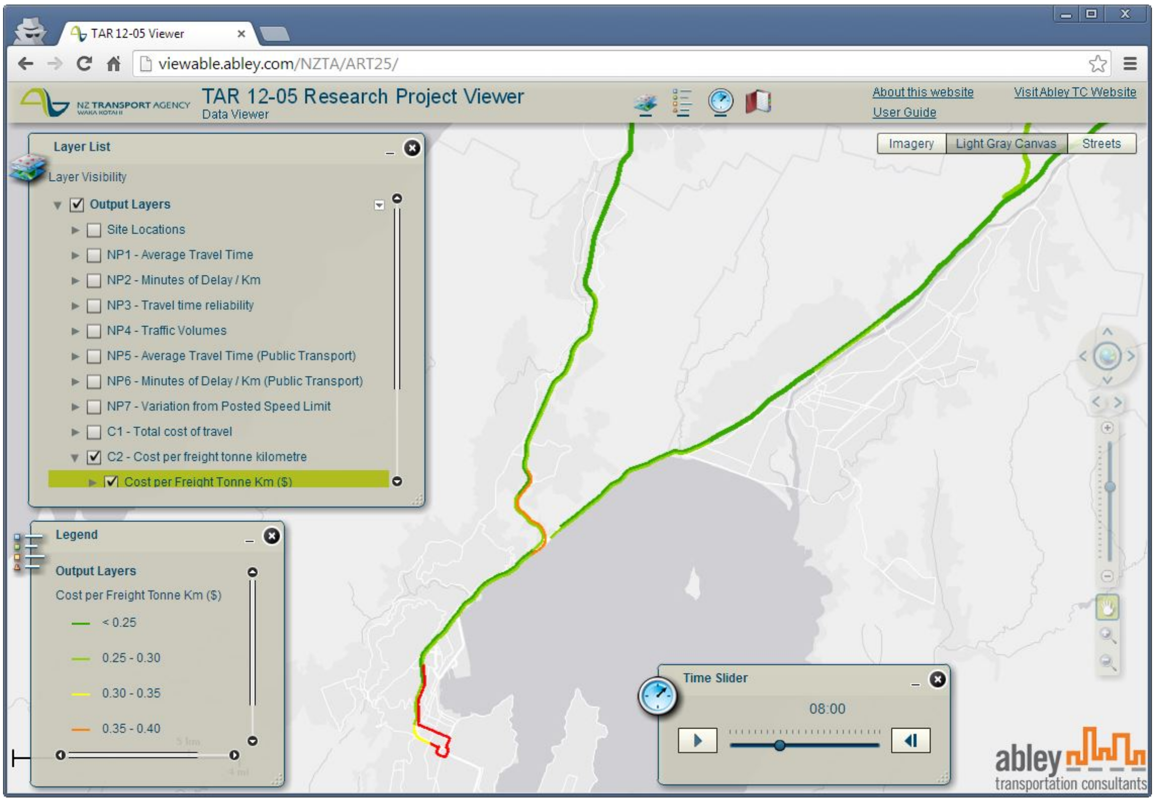
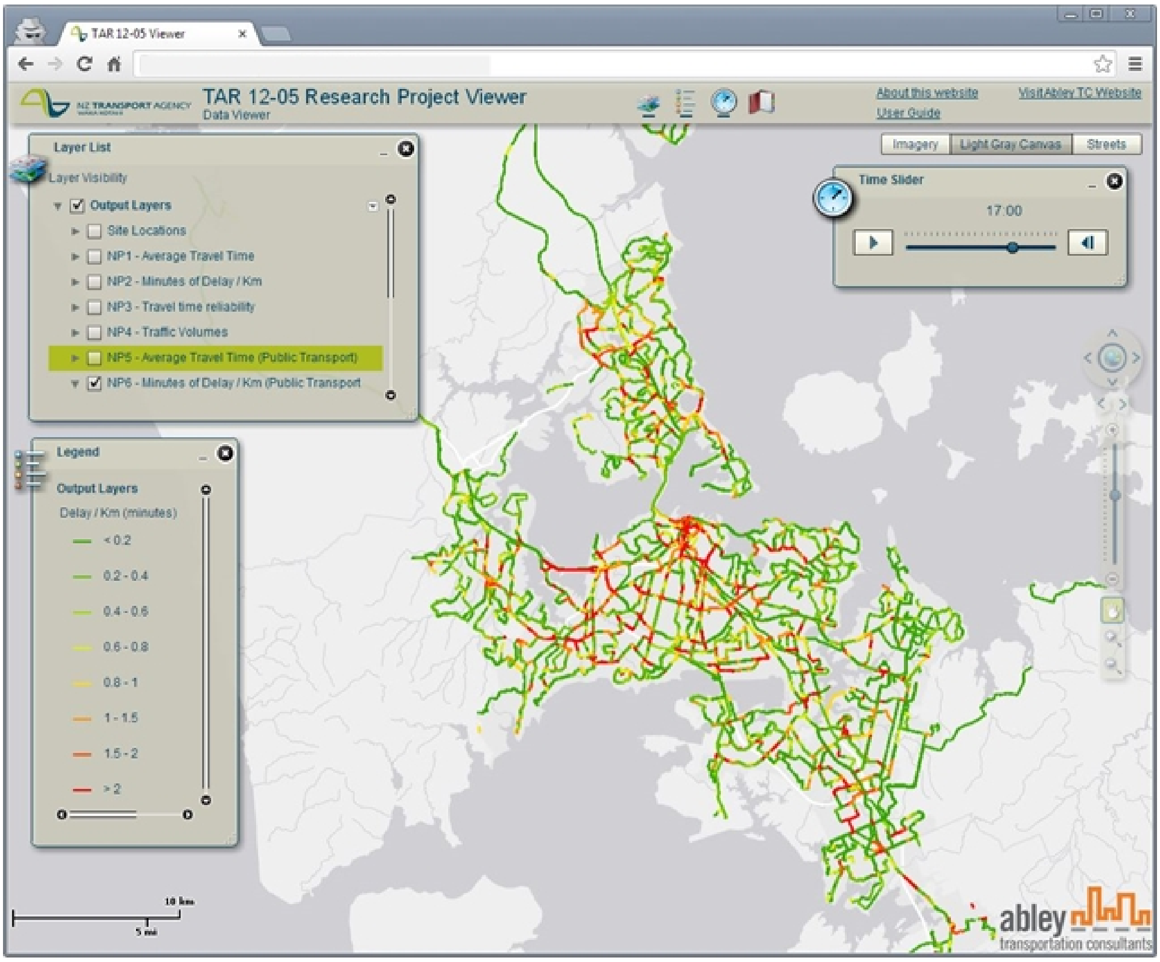
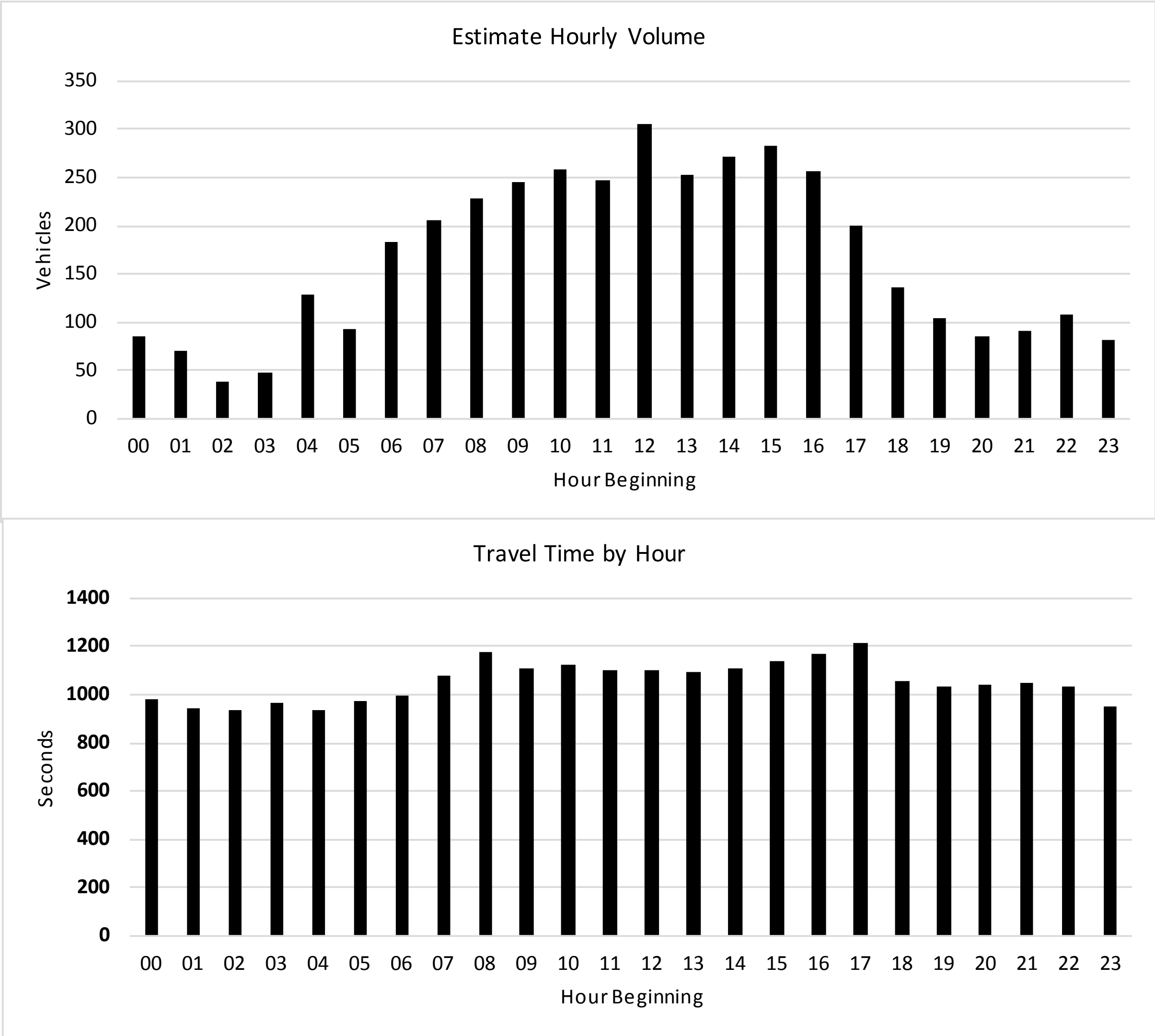


Figure 8.8 Travel-time variability: Auckland PT sub-project



There is the potential to extend the functionality of the proof-of-concept model to include graphics showing daily variations (some of the more meaningful examples may include travel time, speed, traffic volumes or VKT). Figure 8.9 provides two examples of this data, one for estimated hourly volumes and one for travel times to demonstrate variability across the day. These pop-up graphics can be presented in a pop-up window within the proof-of-concept model; however, this functionality is not included in the live webviewer.

Figure 8.9 Graphical display of data examples



8.2 Model validation

A significant amount of effort was directed at data validation in the development of the proof-of-concept model. Every effort was made to ensure the validity of all data published in the model; however, the model included an extensive quantity of input data from each of the four sub-projects and presented a broad and diverse range of indicators derived from this data. It was not possible to comprehensively check all of the published outputs, but this section of the report documents the extent of validation which was undertaken.

Three separate stages of data validation were completed as follows:

1 Initial check of raw data from supplier

2 Check indicators derived from data

3 Re-check indicators within the web viewer.

The initial check of raw data from each supplier included comparing the speeds or travel times provided to the posted speed limit, to ensure they were representative of the likely speed environment. Where both travel times and speeds were supplied, the CAS road centreline lengths were extracted to ensure that these reconciled with those inferred from the data. Raw data was also checked for completeness and where it was found to be incomplete, this was highlighted.

The indicators derived from the datasets were calculated using the methodology specified in chapter 6 of this report. Most calculations were implemented by models which could be automated within the GIS environment. Provided there was no substantial change in the underlying centreline road segments or how the data was recorded, this allowed for a quick turnaround of indicator outputs when new data became available. The output indicators wereexported into Microsoft Excel spreadsheets alongside the raw data for each supplier, and the methodology was replicated within this format to validate the GIS model calculations.

After this model validation check, a further check against external data sources was undertaken where possible. The AADT counts were spot checked against Transport Agency and Auckland Transport count databases, and the hourly estimated traffic counts checked against Transport Agency surveyed traffic counts for all telemetry sites for which data was available in the Waikato region.

Following this data validation, the data was uploaded to the proof-of-concept web viewer, and then a number of additional validation and sensibility checks were undertaken. First, a number of links were extracted and the underlying calculation rechecked to verify that the inputs and outputs followed the methodology described in chapter 6 of this report. Second, visual validation was undertaken by systematically working through each layer for each data supplier and checking the underlying trends between road segments and between different times of the day. The visual validation and other checks undertaken prior to the publication of the model were as follows:

- Speeds during uncongested times of the day should be of a similar order to the posted speed limit. If they were significantly less, than this should be able to be attributed to the physical and/or operational environment.
- Measures of congestion and variability should be higher during peak periods of the day, and generally consistent between the morning and evening peak periods (acknowledging that this trend was likely to be less evident or not evident at all on some rural road segments).
- The relativity between traffic volumes on corridors were in line with the intended function and travel demand for each corridor, (largely informed by local knowledge in each study area).
- Extreme values for each indicator (including negative values) were checked to ensure they were representative and not erroneous.
- Indicators that generally increased or decreased relative to VKT should follow the same general trends as the published VKT results.
- Colours set to display each indicator visually demonstrated the variability in the underlying data over time and across the study area.
- The data should be complete in terms of geographic and temporal coverage to ensure that no data was lost between the GIS model outputs and the web viewer.
- The web viewer should be fully functional and user friendly.

9 Risk assessment and business case

9.1 Introduction

This chapter describes the development of a high-level business case for the roll-out of the proof-of-concept model at a nationwide level. The objectives were to:

- assess the opportunities and risks involved in liaising with third party suppliers
- recommend considerations towards engaging with third party suppliers
- recommend considerations towards determining a pricing model.

As part of the business case development, a facilitated workshop was held with the Steering Group on 27 November 2013. This workshop assisted in the identification and evaluation of risk and benefits associated with procurement, data management, the proposed model and model delivery within the Transport Agency.

The risk assessment, set out in section 9.2, presents 15 key risks, discusses their significance and proposes mitigation measures arising from the workshop dialogue. A detailed description of the risks, their relative significance and mitigation methods is provided in appendix D.

Section 9.3 details the outcomes of consultation with Transport Agency procurement representatives and emerging technology data suppliers. As well as discussing general procurement matters, key objectives of the consultation were to understand the significance of the risks in the marketplace and how they might be mitigated.

Section 9.4 sets out the business case considerations for a rollout of the proof-of-concept model into a nationwide tool. This provides recommendations to the Transport Agency relating to a number of matters highlighted through the risk assessment and consultation processes.

A summary of the key findings of the risk assessment and business case development, which address the three objectives specified above, is included in section 9.5.

9.2 Risk assessment

9.2.1 Identification of risks

Risks were considered to fall into one of four broad categories: procurement and third party engagement risks, data management risks, model inputs and outputs risks, and model delivery risks. Within these four categories, 15 risks identified as having the most relevance to the successful roll-out of the proof-of-concept model became the basis of the risk assessment. These risks, which were reviewed by the Steering Group and subsequently discussed and evaluated through a risk assessment workshop process, are:

- Procurement and third party engagement risks:
  - frequency of data feeds and model updates
  - timeliness of data supply
  - data costs
- Data management risks
  - incomplete datasets

  - Transport Agency data storage and processing capacity
  - intellectual property
  - privacy
- Model inputs and outputs risks
  - potential for indicators to change
  - extent of PT data
  - extent of Bluetooth coverage
  - GPS data sample size and sources
  - lack of people throughput data
  - currency and quality of road centreline data
- Model delivery risks
  - synergy with other Transport Agency workstreams
  - integration of geospatial data.

9.2.2 Risk evaluation

To assess the risks, an approach consistent with the general guidance contained in NZ Transport Agency (2004b) was adopted, using the simple qualitative risk matrix shown in figure 9.1. This matrix was considered more appropriate at this stage of the research project than the quantitative matrix typically applied by the Transport Agency to infrastructure projects.

Figure 9.1 Risk matrix

		Consequences				
		Insignificant (1); Minor (10); Medium (40); Major (70); Substantial (100)				
Likelihood	Almost certain (5)	Low	Medium	High	Extreme	Extreme
	Likely (4)	Low	Medium	High	High	High
	Possible (3)	Low	Medium	Medium	High	High
	Unlikely (2)	Low	Medium	Medium	Medium	High
	Rare (1)	Low	Low	Medium	Medium	High

A risk assessment workshop was held in Wellington at the Transport Agency offices on 27 November 2013 with the Steering Group and research team. Participants included representatives of the Transport Agency, MoT, Auckland Transport, Abley Transportation Consultants and URS New Zealand Limited.

The workshop considered and evaluated the potential risks to the successful delivery of the model if it were to be rolled out from a proof-of-concept to a national operational model. Potential mitigation measures were also identified. The workshop did not consider the risks associated with individual datasets but instead focused on the broader risks associated with various emerging technologies in the New Zealand marketplace.

The following sections provide an overview of each risk and the proposed mitigation measures. The full risk register is included in appendix D.

9.2.2.1 Frequency of data feeds and model updates

Data will be sourced from a number of third parties, each with varying processing or supply schedules. The model can be set up to receive and process inputs on a regular basis, which could be customised to the dataset and/or the Transport Agency's requirements. The model is not expected or required to deliver real-time reporting, but near real-time reporting may be desirable for some Transport Agency business functions.

The frequency of data feeds should ideally be tailored to the usage of the indicators. Various Transport Agency business functions have different reporting requirements, for example data used for strategic and planning purposes is often required only annually. It was agreed with the Steering Group that data feeds need to be received at least quarterly, and preferably monthly, to support the Transport Agency's immediate needs. Flexibility should be maintained to allow for more regular updates if available; however, the workshop participants noted that less frequent updates from key data sources would be acceptable as it was better to receive good data less frequently than not at all. In setting these schedules, consideration needs to be given to the effect the frequency of data feeds has on processing costs.

If flexibility in terms of the frequency of data feeds cannot be provided, this introduces a risk to the project for some, but not all, potential users in the Transport Agency. This risk can be mitigated through early engagement with data suppliers and enforced through contractual provisions specifying minimum service standards with regard to the frequency of data feed updates.

9.2.2.2 Timeliness of data supply

The biggest challenge to the research project was the timely supply of data from third parties. This potentially posed a significant risk to the model and was of particular concern where there was an element of post-processing required to aggregate data and/or protect the privacy of the underlying data. Given that the tool was not expected to provide real-time data and the primary use of the data would be for retrospective review for planning purposes by both the Planning & Investment (P&I) and Highways and Network Operations (HNO) teams, the consequences of delays in receiving data were not considered major. However it was acknowledged that this could be highly frustrating.

It was also noted that the model would be used for 'coarse-grain' analysis of the SH network, rather than for looking at specific problems or locations (eg the performance of a specific intersection). In these cases H&O would instead commission site-specific monitoring to obtain this data.

Overall, it was considered that timeliness risks could be mitigated by early engagement with data suppliers, use of fixed templates and clearly specified delivery expectations. An additional incentive to the supplier would be the short-term nature of any contract, as the Transport Agency could choose not to renew the contract if a data supplier did not perform.

9.2.2.3 Data costs

At the time of the research, some suppliers did not have pricing models for selling data in the format and frequency required for the model, and so the potential costs of data were relatively unknown. In addition, rapid changes in technology, coverage and uptake rates can lead to changes in data costs.

There is a risk that suppliers may be reluctant to commit, in the medium to long term, to procurement agreements until they understand their actual costs, and equally, the Transport Agency does not wish to be locked into long-term contracts that prove to be expensive and/or inflexible. However, it has been suggested that increased competition in the market may turn this into an opportunity.

The proposed mitigation, supported by the Steering Group, is to enter into short-term contracts. This will ensure there is some flexibility to modify the datasets, in the event that indicators change (see section 9.2.2.7). Careful analysis of the value associated with each third party dataset should also be undertaken.

9.2.2.4 Incomplete datasets

It is expected that all datasets will have incomplete or unusable data due to gaps in coverage, low sample sizes and reliability issues, for example due to hardware or communications failures. This reduces the value of the model, especially when comparing datasets and network performance at different locations or between time periods. It is important to consider ways of independently validating data, particularly for incomplete datasets. The ability to use other spatial and non-spatial datasets for this purpose should be considered.

The workshop participants considered that, at least during the start-up and development of the tool, reliability issues should not be used to exclude the purchase of data, particularly where the data is important for a key indicator. The proposed mitigation is to put minimum service standards in contracts and document standards for new technologies.

9.2.2.5 Transport Agency data storage and processing capacity

All the datasets collected and subsequently processed within the model, must be stored and archived so that they are available for historical comparisons and future interrogation. The cost of external data storage is relatively low compared with the costs of processing, retrieving and maintaining data in-house, and the Transport Agency currently externalises digital data processing and storage.

There is a minimal risk associated with not being able to archive large quantities of data and a minimum of five years of data should be archived at any time. Any residual risk can be mitigated through smart and efficient system design, and by the Transport Agency contracting out services to archive and/or process data.

9.2.2.6 Intellectual property

The issue of the ownership of intellectual property is yet to be considered in detail by the Transport Agency. It is expected that the ownership of raw data provided by third parties will remain with the supplier; however, it is important the Transport Agency is not constrained in the use of this data. The Transport Agency may wish to use the data for a wide range of purposes and expect to be considered as the primary source of data for the whole sector.

It will be important to ensure that any contract does not limit the Transport Agency's use of the data, particularly due to privacy and commercial sensitivity concerns. The workshop participants discussed the possibility of the Transport Agency investing in and developing their own data sources in order to mitigate any intellectual property and data ownership concerns. Any risks can also be mitigated through early engagement with suppliers and clear contractual terms.

9.2.2.7 Privacy

Controls will need to be in place to ensure the privacy of data is maintained. Ideally, the data provided by third parties should be in a format that does not allow the identification of individual vehicles or persons, although it is plausible that some degree of identification may be beneficial for data validation and cleaning. This will need to be considered when determining the level of pre-processing undertaken by the data supplier.

As the Transport Agency also has an enforcement role, there will need to be a clear separation between business units to ensure no concerns arise regarding the use of the data for enforcement purposes. This could be achieved through a memorandum of understanding addressing privacy concerns and/or contracting a third party to manage data privacy. Privacy concerns may also be alleviated through high-level engagement with industry groups undertaken by senior Transport Agency management.

9.2.2.8 Potential for indicators to change

This research has identified a set of 23 monitoring indicators (presented in table 7.1) that meet the Transport Agency's business case approach. These indicators could still change, particularly when the Transport Agency's HNO Performance Management team becomes established and integrated with other functional teams.

Should the need arise for new or altered indicators, the Transport Agency should first test whether these can be measured from the current or emerging datasets, prior to being rolled out across the organisation. Short-term data contracts and variation provisions will also ensure there is flexibility if data requirements change to support a new or modified indicator set within the model.

9.2.2.9 Extent of public transport data

Data from Auckland and Wellington PT agencies is available, but in different formats. PT GPS data from some other regions is collected, but is not readily available. As it becomes available, the GPS data from each region is almost certainly going to be supplied in different formats with varying underlying assumptions.

Complete PT coverage throughout the country is unlikely to be achievable but the workshop participants considered there was sufficient value in having Auckland and Wellington data. The future inclusion of Christchurch PT data would also be highly desirable. The variability and availability of PT data is not a major concern for the workshop participants, noting that the overall focus of the indicators is the SH network, which coincides with only a small proportion of PT routes.

9.2.2.10 Extent of Bluetooth coverage

Currently there is limited coverage of Bluetooth detectors across the SH network. Some Bluetooth detectors on the current network are positioned some distance apart, particularly on the Waikato rural network. The results of the analysis in the proof-of-concept model are weighted across the combined corridors between adjacent detectors and are therefore not directly attributable to each road segment. If Bluetooth detectors are not installed across the country at a reasonably fine-grained level, there is a risk that the proof-of-concept model may be of limited value.

The use of WiFi as an alternative technology to Bluetooth was considered. As WiFi-enabled devices do not transmit continuously they are not suitable for vehicle tracking, but can be used as 'add-ons' to Bluetooth detection devices. The consensus from the Steering Group was that Bluetooth has considerable momentum in the marketplace both in terms of device uptake and the rollout of detection hardware and is likely to be around for some considerable time.

Although the current limited extent of Bluetooth coverage has a major impact on the ability to deliver network-wide indicators, this will be mitigated, to some extent, through ongoing engagement with Bluetooth providers regarding the growth of the detector network and through a strategic focus within the Transport Agency to roll out Bluetooth deployment and continue investment across the network.

9.2.2.11 GPS data sample size and sources

The sample size of GPS data is relatively small and tends to over-represent commercial vehicle fleets. It is not possible to reliably aggregate data from alternate suppliers as there is no transparency regarding the composition and industry sector of the vehicle fleets that are supplying data. GPS data, however, does support fine-grained analysis as road segment lengths can be specified to meet the needs of the model.

While it may be feasible to integrate GPS as fine-grained data nested within Bluetooth, the Steering Group and research team agreed there was limited value in doing this due to the difficulties in matching GPS data to Bluetooth detector locations, the underlying biases in fleet composition of commercial GPS data and the margins of error which might be introduced due to low Bluetooth and GPS sample rates. Subsequently, the proof-of-concept model did not test the integration of GPS and Bluetooth data.

The variability of GPS data can be mitigated through ongoing engagement with data suppliers and regular analysis of the raw data to better understand changing trends (for example, sample rates and fleet composition) over time. Statistical analysis can also be applied to take into account known biases in the data, as well as helping to understand the significance of these biases.

9.2.2.12 Lack of people throughput data

Mobile technology cannot currently support a measure of people throughput. While this indicator is desirable, it is not considered to be critical to the expansion of the proof-of-concept model. In the near future, integrated PT ticketing and mobile opt-in applications will provide promising sources of people throughput data to better understand the performance of transport networks. There are initiatives within the Transport Agency to keep abreast of these developments.

9.2.2.13 Currency and quality of road centreline data

The model is based on CAS road centreline data which is updated annually. This is problematic where new roads open (for example, as occurred when the Te Rapa Bypass component of the Waikato Expressway opened) or if the road environment changes (for example, changes to the alignment, speed limit, or function). In the development of the proof-of-concept model, it was also found that some underlying attributes of this data were not completely reliable, particularly for non-SH roads which are updated less frequently. Ongoing data validation and cleaning of the road centreline will therefore be an important step to ensure an accurate and reliable dataset for the model.

There are other centrelines available (including the Transport Agency owned and maintained SH centreline) and the Steering Group acknowledged there was no one definitive centreline dataset; each having advantages and disadvantages, particularly for analysing different data sources or generating particular transport monitoring indicators. If the decision is made to continue with the CAS centreline, it would be desirable to receive more regular updates. A process for providing feedback and correcting identified errors should be established.

9.2.2.14 Synergy with other Transport Agency workstreams

The Steering Group provided positive feedback on an early draft of the proof-of-concept model accompanying this research and while there was consensus that it met the project objectives, the model should ideally be integrated with other Transport Agency initiatives including the emerging transport data warehouse (TDW).

Maintaining flexibility within the model and including graphs, tables and other meaningful ways of displaying data, increases the likelihood that the product will deliver value to the Transport Agency over the long term. It is recommended that the development of the tool be communicated widely within the Transport Agency to scope opportunities for synergies with existing tools and future Transport Agency initiatives, including the TDW, to minimise the risk of duplication of effort across Transport Agency business units, and to realise efficiencies where similar information needs exist.

One such example is to develop a national process for managing speed limit changes on the SH network to ensure that speed limit data is continually up to date. This would then feed into the proof-of-concept model and other underlying data sets (such as Transport Agency RAMM and KAT data).

9.2.2.15 Integration of Transport Agency geospatial data

There is considerable value to the Transport Agency in rationalising their geospatial datasets, including road centrelines and underlying centreline attributes. There is a risk that the expansion of the proof-of-concept model in isolation from other geospatial initiatives will result in considerable duplication of effort, as each dataset is maintained independently.

By developing the proof-of-concept model based on the CAS road centreline, the likelihood of this risk is minimised; however, further opportunities for better integration should continue to be sought.

9.2.3 Summary of risks

A summary of the risk register (included as appendix D) is presented in table 9.1. Each of the risks is listed from highest through to lowest score. None of the risks fell into the 'extreme' category, although the following four risks were categorised as 'high':

- data costs
- intellectual property
- privacy
- currency/quality of CAS road centreline data

The first three listed above relate directly to procurement and engagement with data suppliers and were therefore included as points of discussion in consultation with potential data suppliers. The key findings arising from this consultation are reported in section 9.3.2.

A further eight issues were categorised as posing a 'medium' risk and the remaining three were categorised as 'low' risk as specified in table 9.1.

Table 9.1 Risk assessment summary

	Risk	Consequence		Likelihood		Score (C x L)	Risk category
		Description	Rating (C)	Description	Rating (L)		
c	Data costs	Major	70	Possible	3	210	High
f	Intellectual property	Major	70	Possible	3	210	High
g	Privacy	Major	70	Possible	3	210	High
m	Currency and quality of road centreline data	Medium	40	Likely	4	160	High
j	Extent of Bluetooth coverage	Major	70	Unlikely	2	140	Medium
n	Synergy with other Transport Agency workstreams	Major	70	Unlikely	2	140	Medium
o	Integration of geospatial data	Medium	40	Possible	3	120	Medium
k	GPS data sample size and sources	Medium	40	Unlikely	2	80	Medium
b	Timeliness of data supply	Minor	10	Likely	4	40	Medium
d	Incomplete datasets	Minor	10	Likely	4	40	Medium

	Risk	Consequence		Likelihood		Score (C x L)	Risk category
		Description	Rating (C)	Description	Rating (L)		
a	Frequency of data feeds and model updates	Minor	10	Unlikely	2	20	Medium
e	Transport Agency data storage and processing capacity	Minor	10	Unlikely	2	20	Medium
l	Lack of people throughput data	Insignificant	1	Almost certain	5	5	Low
h	Potential for indicators to change	Insignificant	1	Likely	4	4	Low
i	Extent of PT data	Insignificant	1	Likely	4	4	Low

9.3 Transport Agency and third party consultation

Consultation was undertaken with the Transport Agency's procurement staff and emerging technology data suppliers to discuss procurement and other commercial considerations. Additional consultation with some government departments was initiated but this did not provide additional insight or value to the business case for this application.

The information gathered during consultation informed the business case considerations reported in section 9.4.

9.3.1 Transport Agency procurement

A meeting was held with a number of Transport Agency staff to discuss the procurement methodologies used within the Transport Agency, and to decide on the most appropriate for the datasets and suppliers of interest. The most relevant contract terms used by the Transport Agency are those for the procurement of physical works, for professional services and for research. There are additional procurement systems for administrative goods and services, and for IT systems, but these are not analogous to the data provisions required for the proposed model, and were therefore not considered further.

A form of contract based on a research model could be considered; however, this contract contains requirements for the establishment of steering groups and peer review requirements. Given the commercial nature of most of the data suppliers, these provisions were not considered germane to a data supply contract.

While most emerging technology data suppliers are selling data without hardware requirements, Bluetooth data suppliers offer options to lease or purchase the Bluetooth detector hardware and any associated software that may be required. The Transport Agency could purchase the hardware, receive full rights to the data and have a maintenance agreement directly with the supplier, or they could lease the hardware and receive a data supply over a fixed term. It is also possible to lease the hardware and then purchase it outright at some later date.

For straight data procurement (without hardware requirements), it is proposed that the most appropriate form of contract for digital data supply would be one based on the provision of professional services. There are two forms of this contract: a standard (or long-form) contract and a short form contract. Both are based on the IPENZ Conditions of Contract for Consultancy Services (IPENZ 2009), often referred to as the General Conditions), and assume a relationship between the Transport Agency (as Client) and a

Consultant. The short-form version is for contracts with a value generally below $250,000, which can be tendered or direct appointed if justified and approved.

As discussed later in this section, the likely involvement of three parties in the supply and processing of data for the model (Transport Agency, a Supplier and a Consultant) means that it may be appropriate to modify the definitions to ensure the role of each of the parties is clear.

There are a number of examples of data procurement within the Transport Agency including:

- traffic counts – a relatively long-standing contract that is tendered through Tenderlink. The scope covers both maintenance of stations and supply of data
- GIS road centreline – paid to a third party as an annual licensing fee.

In general, procurement of data (of any type) within the Transport Agency has been ad hoc – as dictated by the requirements of the time and the nature of the data. As a result, the data arrives in proprietary formats and remains in silos. The challenge and opportunity for this project is to ensure that the data meshes with other data initiatives at the Transport Agency, such as the TDW, and that the geospatial representation used across the Transport Agency is consistent.

9.3.2 Consultation with data suppliers

Consultation was undertaken with a number of organisations that provide commercially available data from emerging technology sources. A total of 12 organisations were approached, including GPS data suppliers, Bluetooth data suppliers, PT operations agencies and consultants.

Eight of the 12 organisations formally responded to the following six questions:

1. If the Transport Agency were to engage you to provide a data feed with monthly updates, what sort of pricing models would you consider? For example, this may include such pricing models as a lump sum per data feed, piecemeal rates based on geographic coverage, quantity of data supplied, or perhaps some combination thereof.
2. Do you have any preference for or restrictions regarding the length of contract (eg six months, 12 months, two years, five years) you may wish to enter to supply a monthly data feed?
3. In terms of procurement would you be happy to engage directly with the Transport Agency or prefer to manage the supply of data through a third party (eg a consultant or local agent)?
4. Are there any specific privacy concerns around data supply which would need to be addressed contractually and what is the nature of these concerns?
5. Are there any specific intellectual property concerns around data supply which would need to be addressed contractually and what is the nature of these concerns?
6. Other than privacy and intellectual property are there any other commercially sensitive issues which would need to be addressed (please specify)?

The responses were aggregated and anonymised to protect the commercial interests of each respondent. The responses to questions one through three have been pooled together and included in section 9.3.2.1 and an overview of the responses to four through six are presented separately in the following sections.

9.3.2.1 Procurement considerations

A variety of existing or likely pricing models were proposed or preferred. Two respondents suggested that the form of a pricing model would have to be evaluated on a case-by-case basis and two others responded that they were open to any suggestions and were keen to be flexible in any contractual negotiations with the Transport Agency.

In Bluetooth applications, both purchase and lease options are available for procuring Bluetooth detection hardware. In GPS applications, lump sum, piecemeal (based on the length of the corridor and the volume of data) or a combination of these were proposed; however, there was a general willingness to be flexible in considering pricing models that would suit all parties.

The preferred length of contract from two respondents was for a minimum period of 12 months; however, the majority of respondents were flexible in this regard and were happy to accommodate one-off data supply needs through to long-term contractual arrangements. One respondent acknowledged that the minimum term would be dependent on the level of upfront investment required to set up the necessary processes, and another respondent suggested that the best value for money to the Transport Agency would be achieved through a longer term (three to five year) contract.

Those respondents who currently engage with an external consultant as part of their procurement arrangements with the Transport Agency have a strong preference for maintaining the status quo and have very good reasons for continuing this arrangement. All other respondents generally have a preference for dealing directly with the Transport Agency but in some (but not all) cases, may consider using an external agent or consultant where it is mutually beneficial to do so.

9.3.2.2 Privacy considerations

Most respondents do not consider privacy an issue as their internal data management systems protect both the privacy of individuals and any contributing organisations whose vehicle fleets supply raw data. It is an industry standard for both Bluetooth and GPS data provision that the privacy of individuals is protected and only anonymised data is sold.

Despite having safeguards and tight controls in place, two respondents emphasised the importance of the privacy of individuals and/or organisations that supply data. These concerns included the potential for individual persons to be identified, the potential for enforcement, and the potential that competitors (either of the data supplier or the contributing fleet) could access the data. In both cases, a non-disclosure agreement with the Transport Agency and any consultants involved in the management or post-processing of data would be proposed as part of any procurement arrangement.

9.3.2.3 Intellectual property considerations

The data suppliers invariably own the intellectual property (IP) rights associated with the raw data they supply; however, in most instances there were no concerns or claims over any new IP relating to post-processing or further development using the supplied data.

One respondent claimed that the data was provided under an exclusive license and must be returned and therefore the question of where the rights for new IP sit is somewhat unclear, and another respondent expressed an interest in discussing joint IP rights with the Transport Agency if the occasion arose but remained flexible to work in with the Transport Agency as far as possible.

9.3.2.4 Other commercial sensitivity considerations

The key commercial sensitivity issue raised by a number of respondents echoed those issues previously documented as privacy considerations in section 9.3.2.2. Specifically these related to the respondent's data being disclosed to one of their competitors. In one instance, the respondent made it clear that contractually they would require their data to be protected from disclosure to other parties not authorised by them and would reserve the right to supply their data to other interested parties.

One respondent was keen to limit or control the number of data feeds provided, to reduce the risk of privacy and commercial sensitivity breaches, and another respondent mentioned that steps would need to be taken to ensure that organisations in direct competition with each other could not access each other's data.

9.3.3 Opportunities

Following both the risk assessment workshop and direct consultation with the Transport Agency and data suppliers, it was evident that there are significant opportunities for the Transport Agency in rolling out the model. These opportunities largely offset some of the key risks highlighted in the risk assessment process and indeed some had emerged from the risk assessment workshop discussions.

The opportunities are listed below:

1 Suppliers are investing in expanding their coverage and services within New Zealand, providing a strong indication as to the future longevity of the underlying technologies.

2 Suppliers are generally willing to be open and flexible in procurement arrangements with the Transport Agency and are keen to embrace opportunities in this regard.

3 While being relatively new, the emerging digital data market is competitive with multiple Bluetooth and GPS suppliers actively selling digital data in New Zealand. This provides plenty of scope for engaging with multiple suppliers to make the most of the marketplace opportunities.

4 Some suppliers are investing in research as to how their data can be used for new applications in New Zealand to benefit the Transport Agency, local authorities and other clients. This is a reflection of the rich appreciation in the industry that emerging data sources can deliver considerable value to the New Zealand transportation sector.

5 The proof-of-concept model supports the Transport Agency's initiative to combine spatial information in a central location and has been developed to capitalise on existing datasets that are being widely used within the Transport Agency.

6 The proof-of-concept model provides a common source from which a range of Transport Agency business units can be informed, so there is the opportunity to avoid duplicating development work and standardising data inputs for subsequent analysis and reporting.

7 There are synergies between this project and other initiatives which the Transport Agency is investing in, including the development of the TDW.

9.4 Business case considerations

This section discusses the matters that need to be considered when setting in place contracts for the supply of data. In any contract, a clear understanding and correct use of defined terms is imperative to minimise the potential for ambiguity. The existing forms of contract used by the Transport Agency, are primarily based on IPENZ (2009) and often referred to as the 'General Conditions'. These forms of contract contain standard definitions that are not repeated here, except where they are considered to be relevant and required for the discussion, or where alternate definitions may be more appropriate.

One example where an alternate definition is recommended is in the definition of the parties to the contract. Rather than referring to the parties as the Client and Consultant, the terminology used in this section of the report refers to the Transport Agency by name, where the Transport Agency is the client in the position of purchasing digital information, and to Suppliers, being the digital data suppliers. This convention has been adopted in order to minimise confusion with the use of the term consultant. It is likely that one or more consultants will also be involved in the development of the model and will therefore also be the subject of a contractual arrangement with the Transport Agency (in which case the term Client/Consultant will be appropriate). It is noted that an alternative name for a supplier could be licensor, and could be adopted where it is considered appropriate to refer to a licence agreement.

Using this terminology, the Transport Agency (the Client) would be party to a contract for the purchase of data from a Supplier. The Transport Agency and, potentially, the Supplier, would also be party to a separate contract with a Consultant, for the processing of the data for uploading into the model.

9.4.1 Intellectual property and data ownership

The clear definition of intellectual property (IP) is one of the most important features of any contract document. Even in situations where data is supplied at no charge, the IP rights of both parties to the transaction should be defined. IP provisions must be specified for:

- data supplied to the Transport Agency (referred to in the General Conditions as pre-existing IP)
- data created by the Transport Agency or the Transport Agency's consultants (referred to in General Conditions as new IP, but which could also be defined as derived products).

The IP of data and metadata provided to the Transport Agency by the Supplier must remain with the Supplier. This is a given baseline in any contract and has been reinforced through the consultation with data suppliers. This applies whether the data supplied is raw or processed by the Supplier. The supplied data cannot be on-sold by the Transport Agency nor claimed as the Transport Agency's own. The form of contract will therefore contain clauses such as: 'the Transport Agency acknowledges that all Intellectual Property Rights of the Data are the property of and remain owned by the Supplier' or 'All Pre-existing Intellectual Property shall remain the property of the original owner' (section 9 of the General Conditions).

New IP will be created by the Transport Agency or consultants appointed by the Transport Agency during the processing of data to derive the indicators. The IP of newly created data developed within the Transport Agency should be vested solely with the Transport Agency, and should not lie with the Supplier (eg 'The parties agree that any metadata and derived products which are developed or commissioned by the New Zealand Transport Agency (at its sole expense) will belong to the New Zealand Transport Agency').

In practice, it is likely that a third party, such as a Consultant, will be involved in processing the supplied data to derive the indicators. A separate contractual agreement must be made between the Transport Agency and the Consultant, either in a standard contract form or in the form of a licence agreement, which permits, with conditions, the Consultant to use the data on behalf of the Transport Agency.

Under the General Conditions, any new IP so created would be shared jointly by the Transport Agency and the Consultant (eg 'All New Intellectual Property shall be jointly owned by the New Zealand Transport Agency and the Consultant, and each grant to the other an unrestricted royalty-free license …') (section 9 of the General Conditions). Alternatively, a contract could be agreed that awards sole ownership of any new IP to the Transport Agency. In either event, the Transport Agency will be in a position to on-sell the new data, if appropriate, or make it available to other government agencies.

In situations where data is provided by a Supplier free of charge, it is often a convention that the Licence Agreement would then restrict use of the data to non-commercial purposes only, although this can be considered on a case-by-case basis.

While the General Conditions use the term new IP, an alternative definition that could be considered on a case-by-case basis is that of Derived Products. This term may be appropriate given that the IP being developed takes the ultimate form of a set of indicator values, which could be widely used as an economic performance measure within the wider public sector.

The General Conditions do not contain a definition for metadata, but it is recommended that consideration be given to including a definition in any data supply contract, to minimise ambiguity. For example: metadata means documentation that describes how, when, where and by whom a particular set of data was collected, how the data is formatted, the history of changes (if any), relationships to other data (if any) and any other information that may be used to aid in the identification, description and location of the data.

9.4.2 Confidentiality/commercial interest

For the purposes of this discussion, aspects of confidentiality and commercial interest are considered separately from privacy issues (discussed in section 7.4.3). In any form of contract, information can be confidential to either party. In this case, it is likely that data will be sourced from parties that are commercial competitors in the provision of traffic data, and in some cases, the traffic data that is collected could have commercial value, particularly regarding fleet operations. This has been raised as an issue during consultation with suppliers. It is therefore important that the confidentiality of this information is carefully managed.

The General Conditions contain standard provisions regarding confidential information which are appropriate for the contract between the Transport Agency and the Supplier. These terms will also need to be mirrored in any contract with a Consultant that has access to the data, possibly through the adoption of data-specific non-disclosure or licence agreements.

It is important to note that the definition of 'confidential information' in the General Conditions includes material that is not specifically identified as confidential.

9.4.3 Privacy issues

The collection of digital data has the potential to raise significant privacy issues, particularly as some data, such as Bluetooth data, is collected without the knowledge of the individual. As described in section 9.3.2, most of the suppliers contacted during this research have procedures in place to anonymise the data collected so that it is not possible to identify individual users, thus keeping travel patterns private.

While the General Conditions contain standard provisions regarding confidential information (discussed in section 9.4.2), they do not explicitly refer to the obligations of the parties to protect the privacy of individuals and organisations. It is recommended that this aspect be acknowledged in any contract entered into by the Transport Agency, for example by noting that while the primary obligation for ensuring the privacy of data supplied lies with the Supplier, the Transport Agency would alert a Supplier if any potential privacy breaches were identified.

9.4.4 Insurance

The two main types of insurance relevant to service contracts are professional indemnity and public liability, and the level of insurance held and limit of liability are specified in all contracts based on the General Conditions. The former provides cover in the event of negligent design or deficiencies in the work undertaken by the Consultant; the latter covers injury or damage to property and/or third parties arising directly out of the actions or failure to act on the part of the Consultant in carrying out works under the contract.

Consideration will need to be given to the need for and level of insurance required in any contract between the Transport Agency and a Supplier, where the Supplier is not acting in the role of a Consultant. As the data will be used by the Transport Agency, it may be appropriate that a supplier provides some level of indemnity, in the event that the Transport Agency are required to rectify any errors arising from the data. The required level of cover should be determined taking into account the potential risks associated with the scope of work.

It should be noted that professional indemnity insurance is not 'event triggered' in the same manner as public liability insurance. The case for negligence must be established first and in most cases professional indemnity insurance will not respond until negligence is proven.

Public liability insurance may not be required to be held by the Supplier, as it is unlikely that an error in the data or subsequent processing would result in damage to property or the public. In a comparable situation, contracts conducted under the Transport Agency research agreement do not require public liability insurance. The need for public liability insurance should therefore also be considered, and any decisions on its applicability clearly documented.

These insurance provisions must also be considered in any contract or licence agreement between the Transport Agency and a Consultant.

9.4.5 Pricing models

The clear definition of scope of data provided, and associated costs, are central to any data supply contract, and can be modified to suit the needs of both parties. The standard contract forms used by the Transport Agency contain provision for both fixed price quotes and time writing fees, therefore the pricing of the model is not likely to be problematic. Rather, the quantum of the price (particularly the relativity between different datasets is likely to be the greatest point of discussion.

Given the nature of the data supply in this situation, it is expected that a fixed price quote will be the most appropriate, although this could be made up of both a set, baseline fee (for example a monthly or annual fee), as well as a variable component (for example based on highway network coverage). In general, it would be expected that the shorter the duration of the contract entered, the smaller the component of variable pricing. It can be seen from the information presented above, that there is likely to be a wide range in pricing models. Further information and assessment will need to be made in conjunction with discussions on the detailed scope of the data to be purchased.

9.5 Summary of business case

The facilitated risk workshop identified a number of risks and opportunities associated with the roll-out of the proof-of-concept model. Risks were assessed using a qualitative risk matrix. None of the risks fell into the extreme category. Four risks (out of 15) were assessed to be high, three of which were associated with procurement and the engagement of suppliers. A number of actions were identified that could be applied to minimise the risks, and these all relate to early engagement with suppliers, and the need for the Transport Agency to retain as flexible approach as possible in contractual dealings, particularly in the initial, start-up phase, while the performance indicators and model are being established.

Overall, the assessment concluded that the majority of the risks were manageable, and that there were significant opportunities to be realised by the Transport Agency in rolling out the model.

The existing forms of contract used within the Transport Agency for the procurement of professional services are appropriate forms on which to base a data supply agreement with a Supplier, as they contain the baseline for clear agreement on matters of importance, such as IP, privacy and commercial confidentiality. It is likely that one or more consultants will also be involved in the development of the model, and therefore appropriate contracts between the Transport Agency/Consultant and Supplier/Consultant will be required. These may take the form of data-specific non-disclosure or licence agreements. It is recommended that, initially, contracts be negotiated annually, as this allows flexibility to fine tune the model and the specification for the data stream; however, all parties should be cognisant of the cost and commitment of any initial investment required to set up either hardware requirements or processing methods.

At this early stage, it is not possible to recommend a pricing model that should be adopted. A clear definition of the scope of data being purchased will be required before detailed discussions on the cost can take place, and this is a key success factor for the project. The overall cost of the data, which is unknown, therefore remains as a high risk to the project. The quantum of the price (particularly the relativity between different datasets) is likely to be the greatest points of discussion with suppliers.

The proof-of-concept model provides a common source from which a range of Transport Agency business units can be informed and has been developed to share common elements with other Transport Agency geospatial tools and applications. Thus, there is the opportunity to standardise data sources, achieve synergies between the model and other Transport Agency initiatives such as the TDW, and support the Transport Agency's desire to centralise geospatial resources. This research has the potential to deliver benefits for subsequent analysis and reporting across a range of business units of the Transport Agency while maintaining flexibility so that the model can continue to develop to meet the Transport Agency's future needs.

Discussion with suppliers has been overwhelmingly positive, with the majority of suppliers clearly stating that they are open and flexible to pricing and procurement models as long as privacy and commercial sensitivity matters are satisfactorily addressed. Given the suppliers' interest and willingness to work with the Transport Agency in this emerging and competitive market, there is an excellent opportunity to build strong data-supply relationships with multiple suppliers.

10 Conclusions

This report explored the potential for emerging technologies to inform useful SH network monitoring indicators. In this section the key conclusions arising from this research are discussed.

A range of emerging technologies were initially identified as potentially useful for the purpose of informing SH performance indicators:

- GPS
- Bluetooth
- infrared
- mobile
- laser
- weigh-in-motion
- microwave.

An extensive review of national and international transport monitoring frameworks and best practice literature was undertaken to establish an initial indicator framework against which the identified technologies could be tested (refer chapter 4). This framework was informed by previous work in this area (Denne et al 2013), as well as input from the Project Steering Group.

A review of New Zealand technology applications was also undertaken. It was found that of the technologies initially identified, commercially available datasets could only be sourced from Bluetooth, GPS, mobile and WiM technology providers.

Sample data from a range of technology providers was used to test whether the indicators identified could be sensibly or feasibly generated. Table 10.1 summarises the indicators that could be successfully generated from the emerging digital data sources.

Table 10.1 Indicators that could be generated from emerging data sources

Indicator(s)		Data source	Comments regarding methodology, limitations and assumptions
NP1.1 NP1.2	Average travel time and speed (private)	Bluetooth GPS	A primary indicator provided by the data source.
NP1.3 NP1.4	Average travel time and speed (PT)	GPS (PT operator)	PT GPS data does not readily translate into travel-time or speed data for road links and requires post-processing. This GPS data source is generally less reliable than other data sources.
NP2.1	Minutes delay per km (private)	Bluetooth GPS	This is an indicator of travel-time reliability that requires a measure of free-flow speed or travel time. Free-flow measures can be interpreted from the data source (minimum average traversal times).
NP2.2	Minutes delay per km (PT)	GPS (PT operator)	PT GPS data does not readily translate into travel-time or speed data for road links and requires post-processing. This GPS data source is generally less reliable than other data sources. (see also comments above).
NP3.1 NP3.2 NP3.3	Standard deviation and percentile speeds (15th/85th)	Bluetooth GPS	These indicators must be generated by the data supplier where the raw data sample is not available.

Indicator(s)		Data source	Comments regarding methodology, limitations and assumptions
NP4	Variation from speed limit	Bluetooth GPS	This indicator compares recorded speed to the speed limit (weighted, if required). Good quality speed limit data is required. This is a poor measure of travel-time reliability or variance (compared with delay or other statistical measures) but can be used for speed limit reviews or speed enforcement purposes.
NP5	Estimated hourly volume	Bluetooth	This indicator is generated by correlating known AADT values (weighted where required) against the distribution of Bluetooth sample counts across a 24 hour period to generate estimated hourly traffic volumes. The validity of the output decreases and link length increases and/or where there is a large number of on/off movements. This indictor requires a good source of centreline AADT data.
H1.1-HE1.4	Emission rates (CO, N_2O, PM_{10}, VOC)	Bluetooth	These indicators use estimated hourly volumes, speed data, fleet composition and procedures from the EEM to estimate the rate of emissions per km. Fleet composition is assumed to be 5% heavy as this data is otherwise unavailable.
HE2	CO_2 emissions	Bluetooth	This indicator can be estimated as a function of the vehicle operating costs (see C1.1 and C1.2 below). EEM guidelines specify that the cost due to CO_2 emissions is approximately 4% of vehicle operating costs based on a cost of $40 per tonne of emissions.
S1	VKT by star rating	Bluetooth	KiwiRAP data is combined with VKT to provide a comparison of travel activity on star-rated roads. This indicator can only be generated for rural SH road segments where KiwiRAP star ratings have been calculated.
A1	VKT	Bluetooth	VKT is calculated on an hourly basis by multiplying estimated hourly volumes (see NP5 above) by road segment length.
A2	Total freight tonne kilometres	GPS by class	GPS data with heavy vehicle composition attributes has been used to estimate heavy vehicle km on an hourly basis. The total freight tonne km can then be estimated based upon average net freight load statistics.
C1.1 C1.2	Cost per VKT/total cost of travel	Bluetooth	EEM procedures can be used to convert the VKT and speed data into vehicle operating costs, and deriving travel-time costs from average travel times and vehicle volumes.
C2.1 C2.2	Cost per freight tonne km/total cost of freight travel	GPS by class	EEM procedures can also be applied to convert the heavy commercial VKT and speed data into commercial vehicle operating costs, and deriving corresponding travel-time costs from average travel times and commercial vehicle volumes.

A number of indicators that were initially considered as having potential to be informed by emerging digital data sources were found to be infeasible or impractical, including:

- throughput (people moved)
- peak travel times or speeds (minimum/maximum)
- PT on-time reliability
- network condition and customer satisfaction
- number and rate of serious injuries and deaths
- social cost of incidents.

It was initially thought that 'throughput', or the number of people moving through a transport network, could be generated from mobile phone usage data. Following receipt and analysis of sample mobile data and discussions with providers, it was found that this data was too coarse to be practical and privacy concerns limited the type of data that could be provided (refer section 5.2.1.1). WiM data also proved to be too limited in scope to be useful at a network-wide level and was therefore excluded from any further analysis or consideration.

Through this analysis it was found that only Bluetooth and GPS data sources could be used to extract SH performance monitoring indicators at a nationwide level. These technologies are presently the only data sources which are both available commercially and can provide sufficient network coverage to deliver value network-wide.

Using sample rate expansion, traffic volume was tested as a potential output indicator. It was found that daily traffic volumes for any particular day could not be reliably calculated from GPS or Bluetooth data sources for the following reasons:

- Bluetooth sample rates fluctuate between 15% and 18% depending on the data supplier, network location and time of day, making it difficult to reliably calculate expansion factors for individual road corridors from which daily traffic volumes could be estimated.
- GPS data sample rates vary considerably across the road network with no identifiable correlation between the volume of traffic and the sample rate. It is also not possible to determine whether the GPS data provided is representative of a typical vehicular fleet as suppliers are reluctant to divulge this information for commercial sensitivity reasons.
- The constant rate of change in Bluetooth and GPS technology penetration rates mean that frequent updating of expansion factors for estimating daily counts is required.

While it is not possible to use these technologies to reliably estimate daily traffic volumes, variation in Bluetooth sample rates (or in GPS sources where the fleet composition is known), across the period of a day can be used to estimate hourly traffic flows from known daily traffic counts. This estimation process requires additional data processing to account for seasonal variations and changes in the sampling rate over the course of the typical day. The resultant adjusted output data can be used to examine how traffic volumes vary in this period, and can be adopted as an input into other indicators that require hourly volume or measures of total VKT on the network.

Further consideration and testing of sample data sets also highlighted limitations with data fluctuations and low sample rates on low-volume roads or during off-peak periods. For this reason it was our conclusion that data should be aggregated to both time-of-day periods and across a week or month of data.

A proof-of-concept workflow was tested to determine whether the identified indicators could be practically calculated and displayed in a GIS-based web viewer. This successfully generated all the indicators identified and highlighted a number of further limitations, including:

- Low GPS and Bluetooth sample rates on low-volume roads and/or during off-peak periods meant it was difficult to generate accurate indicators for some road links.
- The variable quality of PT GPS data, both spatially and over time, limited the ability to generate meaningful PT indicators; however, general trends and corridor performance could be visualised in the web viewer.
- The speed limit and AADT data that must be mapped against a road centreline in order for indicators to be generated is not always available or reliable.

- There is a need for data validation checks to ensure the validity of indicator outputs, from the initial check of data inputs though to the development of the web viewer (refer section 8.2).

A number of risks and opportunities associated with the roll-out of the proof-of-concept model were identified through a comprehensive risk assessment process and considered further through consultation. The risks and opportunities related to:

- procurement and third party engagement
- data management
- model inputs and outputs
- model delivery.

Overall, the assessment concluded that the majority of the risks were manageable, and that there were significant opportunities to be realised by the Transport Agency in rolling out the model.

Further consultation was undertaken with both Transport Agency staff and data providers to identify procurement and other commercial considerations that could impact on the business case. The existing forms of contract used within the Transport Agency for the procurement of professional services are appropriate as a basis for digital data supply agreements as they contain the baseline for clear agreement on matters of importance, such as IP, privacy and commercial confidentiality. In the event that one or more consultants will also be involved in the development of the model, appropriate contracts between the Transport Agency/Consultant and Supplier/Consultant will also be required. These may take the form of data-specific non-disclosure or licence agreements.

Discussions with suppliers have been overwhelmingly positive, with the majority of suppliers clearly stating they are open and flexible to pricing and procurement models as long as privacy and commercial sensitivity matters are satisfactorily addressed. Given the suppliers' interest and willingness to work with the Transport Agency in this emerging and competitive market, there is an excellent opportunity to build strong data-supply relationships with multiple suppliers.

The proof-of-concept model provides a common source from which a range of Transport Agency business units can be informed and has been developed to share common elements with other organisational geospatial tools and applications. This has the potential to deliver benefits for subsequent analysis and reporting across a range of business units of the Transport Agency while maintaining flexibility so that the model can continue to develop to meet the Transport Agency's future needs.

11 Recommendations

The recommendations arising from this research project relate to the emerging digital data sources, the indicator framework and GIS viewer, business case development and identifying opportunities for potential further research.

One of the stated objectives of the research was to determine the extent to which emerging technologies could be used to inform useful state highway network monitoring indicators. Subsequently the recommendations in this report have been directed at the NZ Transport Agency as the road controlling authority tasked with managing and operating this key asset. The outcomes of this research will, however, also be of interest to other road controlling authorities, as they are similarly applicable to monitoring the performance of non-state highway road networks.

11.1 Emerging digital data sources

It is recommended that the Transport Agency actively keeps abreast of new technologies and applications that arise in the future, including mobile technology opt-in applications and integrated PT ticketing. ITS technologies and application are continuously evolving with a number of new providers, technologies and capabilities arising through the course of this research. For this reason, it is important that the Transport Agency remains aware of these technologies, but looks for opportunities to leverage data from all new SH ITS applications.

11.2 Indicator framework and GIS viewer

It is recommended that the Transport Agency considers the indicator framework and GIS viewer presented in this report as a starting point for a national-level SH performance monitoring portal.

11.3 Business case development

It is recommended that:

- the Transport Agency undertakes early engagement with suppliers and retains as flexible an approach as possible in contractual dealings, particularly in the initial, start-up phase, while the performance indicators and model are being established
- initially, any contracts with data suppliers be negotiated annually, as this allows flexibility to fine tune the model and the specification for the data stream; however, all parties should be cognisant of the cost and commitment of any initial investment required to set up either hardware requirements or processing methods
- synergies be explored between this research and other emerging Transport Agency initiatives such as the TDW
- when sourcing and managing digital data, the Transport Agency takes the opportunity to integrate this with existing geospatial data and resources as far as practicable.

11.4 Recommendations for further research

It is recommended that:

- the Transport Agency investigate the potential of crowd-sourcing applications (such as mobile opt-in applications) that could be used in the future for measures such as throughput that could not be generated from the technologies covered in this research project. These sources of data will not be restricted by the privacy and security concerns which limit the application of mobile data
- consideration be given to data integration or fusion across emerging data sources in order to correlate data as far as possible across data sets. This may be useful to provide increased sample sizes, and allow for the extrapolation and projection of data at greater levels of detail where applicable. This can be facilitated by centralising the analysis of data sets in a geospatial environment
- further investigation into data quality issues would be valuable to consider the accuracy of the base data and understand the impact of data quality on long-term trending data and the sensitivity of data across different times of day and geographic areas. This may be supported by a comparison of the emerging technology data against data collected by conventional data collection methods such as floating car travel-time surveys and origin-destination number plate surveys
- additional scoping be undertaken to establish the data retention and data storage requirements enabling long-term trending which in turn would support key business decision making. This is important to ensure the longevity of any asset (for example the TDW) developed to store data sets and to maximise the value of this asset.

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Appendix A: ITS and emerging technology literature review sources

	Digital data technology																	Network performance indicators										Summary information				
	Conventional								Emerging																							
Reference	Inductive loops	Infra-red	Radar	Manual counts	Ultrasonic detectors	Pneumatic tube	Video imaging	Piezo-electric cable	Weight in Motion (WIM)	In-vehicle comms system	IR beacon	Blue-tooth	GSM	GPS	Micro-wave	Laser	Fibre optic	Transport volume	Network reliability	Freight industry	Access to transport system	Travel patterns	Transport safety security	Public health effects	Infrastructure & investment	Environmental impact	Price indices	Data collection method/technology used	Frequency of data collection	Size of data collection (geographical)	Size of data collection (number of sample units)	Data use
Australia/New Zealand																																
Austroads (2011) Network performance indicators - next generation. *Austroads report AP-T176-11.*																			x									A summary of a project run by Austroads with the aim of defining a set of network performance indicators to be used for comparing asset management performance across member authorities.				
Austroads (2009) Implementation of national network performance indicators: first round results. *Austroads report AP-T122-09*.																		x	x		x	x			x	x	x	Describes a project run by Austroads to assist road jurisdictions and authorities to implement five new online National Performance Indicators into the existing Austroads National Performance Indicator Program.				
Austroads (2007a) National performance indicators for network operations. *Austroads report AP-R305-07.*																		x	x		x	x			x	x	x	The project aims to establish new operational performance indicators which are suitable for automated measurements and are suitable for adoption to the National Performance Indicator Program.				
Austroads (2007b) Tools that impact network performance: summary report. *Austroads report AP-R313/07.*	x	x	x	x	x	x	x	x	x	x	x	x		x				x	x			x						The project aims to provide a better understanding of the effects on the performance of the entire road network caused by the use of different traffic management tools and proposed operational changes.				
Austroads (2006a) Understanding network performance information provided to road users. *Austroads report AP-R285-06.*	x			x						x		x						x	x		x	x			x			A study aimed at determining performance indicators which all road users would understand and use to make informed road transport decisions, and would also be used by road managers to make decisions relating to the management and operation of the road network.				
Austroads (2006b) A review of road use data integration and management models. *Austroads report AP-R292/06*.	x	x	x	x	x	x	x	x	x	x	x	x		x				x	x	x	x	x			x			Discussion of issues and possibilities of a data framework that integrates road use data and network performance data. The data framework shall be applicable to all road authorities and offer guidance on a way forward while taking into consideration the current outlook of the private and public sector.				
Austroads (2002) Road network asset management: international benchmarking study. *Austroads report AP-R204-02.*														x				x	x	x	x	x	x	x	x	x	x	A comparison of planning practices and road asset management from 12 national and international road agencies against the generic business processes presented in Austroads 'Integrated asset management for road networks'.				
NZ Transport Agency (2011) *State highway traffic data booklet 2007-2011.* NZ Transport Agency.	x					x		x	x									x			x	x			x			Traffic Monitoring System	Continuous and non-continuous for inductive loops	Approximately 1300 sites nationwide		The traffic data in this document is intended to be an approximate indication of traffic flows on state highways in New Zealand. Calculated AADT. Information is also fed into the NZ Transport Agency's Traffic Monitoring System.
NZ Transport Agency (2004) *Traffic monitoring for state highways*. NZ Transport Agency.	x	x	x			x	x	x	x							x	x	x			x	x						Traffic Monitoring System	AADT dependent scheme on data collection frequency. The greater the AADT the more frequent data collection occurs.	70 continuous sites nationwide. The number of other types of sites is not specified.		Sets out policies and procedures for traffic monitoring for the state highway network in a manner that meets NZ Transport Agency goals.

	Digital data technology																	Network performance indicators										Summary information				
	Conventional								Emerging																							
Reference	Inductive loops	Infra-red	Radar	Manual counts	Ultrasonic detectors	Pneumatic tube	Video imaging	Piezo-electric cable	Weight in Motion (WiM)	In-vehicle comms system	IR beacon	Blue-tooth	GSM	GPS	Micro-wave	Laser	Fibre optic	Transport volume	Network reliability	Freight industry	Access to transport system	Travel patterns	Transport safety security	Public health effects	Infrastructure & investment	Environmental impact	Price indices	Data collection method/technology used	Frequency of data collection	Size of data collection (geographical)	Size of data collection (number of sample units)	Data use
Asia																																
Quantum Inventions (2013) *http://cms.quantuminventions.com/* Accessed February 2013.														x				x	x		x	x	x	x			x	Gaps collected information	Continuously and updated every minute	100% of highway network and almost the whole island		Online user interface and sums delivered information to users. System made for the public consumption.
Singapore Land Transport Authority (2013) Accessed February 2013. www.lta.gov.sg/content/ltaweb/en/publications-and-research.html	x		x	x			x	x						x				x	x		x	x	x	x			x	Multiple survey techniques	Continuously from around the city	National coverage; number of samples varies depending on system.		Data freely available on the website to public users in the form of annual research reports and real time traffic information.
Liu, Y and X Jia (2012) *Common vehicle detectors of highway performance comparison and development trend analysis.* Accessed 28 October 2014. www.ier-institute.org/2070-1918/lnit15/v15/478.pdf	x	x			x		x								x	x		x				x	x					Contains none of this information - summary of surveillance mechanisms only.				
Kobayashi, M, K Suzuki and S Nishimura (2011) *Utilization of probe data for traffic flow control.* Accessed 28 October 2014. http://global-sei.com/its/common/pdf/2011_ITSWC_TS132-3167.pdf										x	x			x				x	x		x		x			x		Infrared beacons	Continuously	50,000 units installed in major cities.		Instant data usage via traffic management centres.
Sugimoto, M, K Aoyama and A Kongoh (2001) Improvement of traffic control system by means of infra-red beacon two-way communication, in intelligent transportation systems. In *Proceedings IEEE*, 2000 pp 258-263.										x	x			x				x	x		x	x		x		x		Combination of infrared beacons, GPS and VICS	Continuously	Nearly all Japanese vehicles will have in-car communications.		Instant data usage via traffic management centres. Many uses as seen in the indicator set.
Tiedong, W, F Tingjian and W Jian (2010) Traffic monitoring using floating car data in Hefei. Pp124-126 in *Proceedings of the 2010 International Symposium on Intelligence Information Processing and Trusted Computing.*										x				x				x	x			x						Floating car data technology from vehicle GPS (speed location, direction of travel)	Real time	Hefei, Anhui Province, China. Includes nine freeways and various railway lines. 1,383km road network. Data collected from 500 taxis over 25 days.		Floating car data technology from vehicle GPS (speed location, direction of travel, journey times, traffic reports) used to update traffic information boards and provide traffic information on the internet.
Liu, H and K Zhang (2009) Discrepancy in real-time traveler info websites traffic condition estimation based on rough set theory. Pp1-6 in *Proceedings of 12th International IEEE Conference on Intelligent Transport Systems.* St Louis, MO. 4-7 October 2009.																			x									Performance of different algorithms compared	Every five minutes from GPS systems installed on taxis	Densely used urban arterial road in Beijing. 7.3km road. 10 test vehicles used and 250 taxis used. Study conducted over 7 days.		To compare different algorithms used for interpreting traffic congestion and to propose a new algorithm.

	Digital data technology																	Network performance indicators										Summary information				
	Conventional								Emerging																							
Reference	Inductive loops	Infra-red	Radar	Manual counts	Ultrasonic detectors	Pneumatic tube	Video imaging	Piezo-electric cable	Weight in Motion (WIM)	In-vehicle comms system	IR beacon	Blue-tooth	GSM	GPS	Micro-wave	Laser	Fibre optic	Transport volume	Network reliability	Freight industry	Access to transport system	Travel patterns	Transport safety security	Public health effects	Infrastructure & investment	Environmental impact	Price indices	Data collection method/technology used	Frequency of data collection	Size of data collection (geographical)	Size of data collection (number of sample units)	Data use
Asia																																
Mohan, P, N Venkata and R Ramjee (2008) *Nericell: Rich Monitoring of road and traffic conditions using mobile smartphones*. Accessed 28 October 2014. http://research.microsoft.com/en-us/people/padmanab/nericell-sensys2008.pdf													x	x				x	x			x			x			The study focuses specifically on mobile phone data which uses the accelerometer, microphone, GSM radio, and/or GPS sensors in phones to detect uneven road surfaces, braking, and traffic congestion in developing country (Bangalore) where road conditions vary generally compared to traffic behaviour in developed countries.	GPS tagged cellular tower measurements collected in several drives over the course of four weeks.			The Nericall system can be used to annotate traditional traffic maps with information such as road condition, traffic noise and unpredictable traffic flow. This information would benefit traffic police, road works departments and general road users, for example a user may search for a route that minimises the number of congested intersections for convenience over time/distance optimisation.
Europe																																
NDC (2013) Accessed February 2013. *www.nationwidedatacollection.co.uk/#/surveys/automatic_traffic_counts*.	x		x	x			x	x																				Multiple survey techniques (refer to website for details.)	Done on a client-by-client basis.	Client - specific.		Data is made available to client that commission the work. Public and private clients are catered for.
Sky High (2013) *Information leaflet - Bluetooth technology for vehicle and pedestrian tracking.* Accessed February 2013. www.skyhightraffic.co.uk/downloads/Bluetooth_flyer_grey_small.pdf												x						x	x			x			x			Bluetooth - scanning units placed at roadside.	24-7 data collection - ID codes from active Bluetooth devices log date and time - frequency of logging depends on active devices.	National, user-specific		Analysis and reporting of traffic journey times, origin-destination and routing patterns undertaken live or post-survey.
Thinking Highways (2013) Accessed February 2013. http://thinkinghighways.com												x						x	x			x			x			Bluetooth detection sensors - installed on the road-side including any existing roadside equipment such as VMS signs, gantries or tollbooths where there is an electrical supply.	24-7 data collection.	Primarily on arterial routes and major highways, nationally. Albertis have deployed 150 sensors across 800m of highway.		Provides highly accurate information regarding travel times and incident-detection.
Ott, E (2013) *Timely travel information using GIS.* (undated). Accessed February 2013. www.esri.com/news/arcuser/0799/romanse.html																		x	x			x						Description of the development and implementation of GIS-based traffic monitoring and analysis program called ROMANSE.				
Leduc, G (2008) Road traffic data: collection methods and applications. *EUR technical note JRC 47967*.	x	x	x		x	x	x	x		x		x	x	x				x	x	x	x	x	x	x	x	x	x	GPS and Bluetooth in a floating car system.	GPS: continuous. Bluetooth: as car passes a Bluetooth roadside beacon.	Unspecified		The article details many uses for the information resulting in many benefits.

	Digital data technology																	Network performance indicators										Summary information				
	Conventional								Emerging																							
Reference	Inductive loops	Infra-red	Radar	Manual counts	Ultrasonic detectors	Pneumatic tube	Video imaging	Piezo-electric cable	Weight in Motion (WiM)	In-vehicle comms system	IR beacon	Blue-tooth	GSM	GPS	Micro-wave	Laser	Fibre optic	Transport volume	Network reliability	Freight industry	Access to transport system	Travel patterns	Transport safety security	Public health effects	Infrastructure & investment	Environmental impact	Price indices	Data collection method/technology used	Frequency of data collection	Size of data collection (geographical)	Size of data collection (number of sample units)	Data use
Europe																																
Bacon, J, AR Beresford, D Evans, D Ingram, N Trigoni, A Guitton and A Skordylis (2008) TIME: An open platform for capturing, processing and delivering transport-related data. *5th IEEE Conference on Consumer Communications and Networking*. 2008	x							x										x	x			x	x	x	x	x		TIME (Transport Information Monitoring Environment) project proposes an open platform for capturing processing and delivering transport related data. Aim is to build suitable sensor and network technolog and build reusable software components.	Aim to have continuous life-cycle of data harvesting, processing and display as sensors generate traffic flow and road occupancy readings every four seconds.	Project study area 3.5km by 8km; 112 inductive loop sensors.		Road congestion and traffic pollution have a large negative social and economic impact. The project aims to highlight how these problems can be reduced through investment in the monitoring, distribution and processing of traffic information.
Briggs, D, C de Hoogh, J Gulliver, J Wills, P Elliott, S Kingham and K Smallbone (2000) *A regression-based method for mapping traffic-related air pollution: application and testing in four contrasting urban environments. Science of the Total Environment 15,* no.253(1-3): 151-67.						x												x						x		x		Passive sampling units. For each study area a spatial database was compiled using GIS software. Spatial data included road network, traffic flow, altitude, land cover, monitored NO2 concentrations and meteorology. Pollution monitoring collected data on NO2 concentrations at each study area.		Huddersfield, Sheffield, Northampton and part of London, UK; 80 sample sites in total.		Air quality assessment - measures spatial patterns in traffic related air pollution. Levels of NO2 concentrations measured.
Sarros, G, Y Tyrinopoulos, M Milli, L Locuratolo, V Mizaras, M Chatzathanasiou and A Kortsari (2012) *Open traffic data collection methods: The case of Athens*. ITS, Vienna.	x	x	x		x	x	x	x						x														Multiple sources	Main source of information is floating car (GPS) - continuous.	Athens and its prefectures.		Results expected to deliver an operational platform capable of supporting mobility services, new data collection and processing tools for transport planners incorporating a) Taxi fleet management and traffic information; b) End-user multi modal trip planning and traffic information; and c) an observatory for public authorities and traffic planners.
Graham, A (2012) *The origin of species*. Accessed February 2013. www.its-uk.org.uk/filelibrary/file/ITS-_UK_-NL%20Septembercp.pdf													x					x	x			x			x			This method use data from one of the largest mobile service providers to develop data products for journeys made between cities and towns. The sample data (typically 25-30% of all phones moving in a network), can complement other sources.	INRIX records 20-30% of all movements on every mode every day, 365 days a year, and can locate the start and end of the journey for journeys that involve reasonable numbers of cell-to-cell movements.	To obtain data, 250m by 250m grids were created, counts of how many people are in each grid are made in real-time.		Monitoring people using this technology is useful for traffic management and special events.

	Digital data technology																	Network performance indicators									Summary information				
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Europe																																
INRIX (2008) *Exploring the potentials of automatically collected GPS data for travel behaviour analysis*. Alex Petrie, INRIX.														X				X				X						GPS technology can be used to vehicle locations, speed and time. This technology is most useful if combined with GIS applications - enabling traffic movement to be accurately tracked with an accuracy that could never be reached by manual surveys.		Area for study limited to 20km radius around the town centre of Borlange.		Particularly beneficial in the detection of micro space-time details (short trips, speeds etc), obtaining route choice behaviour information and the extension of the observation period. Weaknesses compared to traditional paper surveys include relatively high equipment costs and costs of post-processing GPS data. Motives for travel use cannot be identified.
El Faouzi, N-E, Henry Leung and A Kurian (2010) Data fusion in intelligent transportation systems: progress and challenges - a survey. Pp4-10 in *Information fusion 12*, no.1: 1-70.	X									X	X		X	X				X	X			X	X		X		X	Data fusion (DF) is collection of techniques by which information from multiple sources are combined in order to reach a better inference. This includes a combination of traditional traffic sensors and other data sources such as cameras, GPS, cell phone tracking and probe vehicles.		Data collected nationally using various data sources. It is considered that information provided by fixed detectors at a certain location alone may not be sufficient and data sources from other sources is required to supplement the detector data to provide a better understanding of the traffic conditions.		It is considered that multiple sources may provide complementary data- for example, a combination of traditional traffic sensors and other data sources such as cameras, GPS, cell phone tracking and probe vehicles. Multi-source data fusion can produce a better understanding of the observed situation by decreasing the uncertainty related to the individual sources. The fusion of data is perceived as an answer to the operational needs of traffic management centres and traffic information operators, allowing them to undertake their work more efficiently.
Steenbruggen, J, MT Borzacchiello, P Nijkamp and H Scholten (2012) Data from telecommunication networks for incident management: an exploratory review on transport safety and security. *Transport Policy 28*: 86-102.													X					X	X		X	X	X	X	X	X	X	Use of mobile phones and the telecommunication network activity in supporting incident management.	Real time continuous.	National - location based services.		To provide increased situational awareness, incident detection, prediction of traffic flow and accessibility of emergency services.
Steenbruggen, J, MT Borzacchiello, P Nijkamp and H Scholten (2011a) Mobile phone data from GSM networks for traffic parameter and urban spatial pattern assessment: a review of applications and opportunities. *GeoJournal 78*: 223-243.													X					X	X			X						Mobile data from GSM network allows the use of very detailed spatial data at lower costs than traditional data collection techniques.		National		Active systems, like GPS-equipped phones used in the Mobile Millennium project, where thousands of users agree to place these phones in their vehicles in order to transmit positioning data and receive free live traffic information look very promising.

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Reference	Inductive loops	Infra-red	Radar	Manual counts	Ultrasonic detectors	Pneumatic tube	Video imaging	Piezo-electric cable	Weight in Motion (WiM)	In-vehicle comms system	IR beacon	Blue-tooth	GSM	GPS	Micro-wave	Laser	Fibre optic	Transport volume	Network reliability	Freight industry	Access to transport system	Travel patterns	Transport safety security	Public health effects	Infrastructure & investment	Environmental impact	Price indices	Data collection method/technology used	Frequency of data collection	Size of data collection (geographical)	Size of data collection (number of sample units)	Data use
Europe																																
Steenbruggen, J, MT Borzacchiello, P Nijkamp and H Scholten (2011b) The use of GSM data for transport safety management: an exploratory view. *Research memorandum 2011-32*.													x						x				x					Telecom data could provide a real-time overview of the current number of people which are affected in case of incidents with dangerous goods, however, more research is required in terms of modelling and validation. Telecom data also has potential for incident prediction in terms of calculating traffic volume and traffic density in combination with other data sources. The technology offers many advantages over existing data collection methodologies but there are still issues with the technology that need to be resolved such as factors which affect accuracy, reliability and data quality and techniques used for validation.				
Jamshidi, H, T Lukaszewicz, A Kashi, A Berghuvud, H Zepernick and S Khatibi (2011) Fusion of digital map traffic signs and camera-detected signs. *5th International Conference on Signal Processing and Communication Systems (ICSPCS).* Honolulu, 12-14 December 2011.										x								x	x			x						Dempster-Shafer data fusion technique. Data fused in MATLAB. Mdata collection consists of merging speed limits reported in digital maps with detected speed limit signs using on-board cameras. A vehicle equipped with a personal computer, a camera with built-in image processing, a GPS receiver and an Autobox (rapid prototyping hardware) was used to gather data. Study covered 15,000 m driving distance in five European countries.				
Rahmani, M (2012) *Path inference of sparse GPS probes for urban networks: methods and applications.* Licentiate thesis. Accessed 28 October 2014. http://kth.diva-portal.org/smash/get/diva2:564999/FULLTEXT02.pdf														x				x	x			x						Introduces a new algorithm for map matching and path inference for sparse GPS probes in urban networks.				
Rahmani, H, N Koutsopoulos and A Ranganathan (2010) Requirements and potential of GPS-based floating car data for traffic management: Stockholm case study. *13th International IEEE Conference on Intelligent Transportation Systems (ITSC)*, Funchal. 19-22 September 2010.														x				x	x			x						GPS probes (GALLILEO project). Sources include taxis, public transport and commercial vehicles.	10 million probes per month. Data collection is almost continuous and in real time. Average frequency 110 seconds, data transmitted every minute.	Stockholm; 1,500 taxis were involved. Data volume is dependent on demand, e.g. more taxis at peak times generates more data.		High quality traffic data for real time monitoring, and management, planning, policy and services. GALLILEO will offer improved accuracy. monitoring and control of the traffic system, including queue and incident detection, dynamic route guidance, real-time multimodal information for travellers, short-time forecasting.
Patroumpas, K and T Sellis (2012) Event processing and real-time monitoring over streaming traffic data. Pp116-133 in *Proceedings of 11th International Symposium, W2GIS,* Naples, Italy, 12-13 April 2012.													x					x				x						Fusion of data from diverse sources for example inductive loops, cameras, mobile devices etc. and flows through heterogeneous networks.	Real time, but the paper identifies differing frequencies for various data sources. For example - buses may only update position information at a turning; cars may update more regularly on a time basis. Frequency of 15 seconds is used on the model for Athens.	Athens used as model; 5,000 sample size quoted and 10,000 simulated for Athens		Real time information for road safety and on line delivery of geospatial traffic analysis. Potential prospects for custom web services for logistics, transport and car navigation systems and social networking. Mobile phones, tablets and PDAs are suggested as the most useful interface for information retrieval. Android app for EPOPS.

	Digital data technology																	Network performance indicators										Summary information				
	Conventional								Emerging																							
Reference	Inductive loops	Infra-red	Radar	Manual counts	Ultrasonic detectors	Pneumatic tube	Video imaging	Piezo-electric cable	Weight in Motion (WIM)	In-vehicle comms system	IR beacon	Blue-tooth	GSM	GPS	Micro-wave	Laser	Fibre optic	Transport volume	Network reliability	Freight industry	Access to transport system	Travel patterns	Transport safety security	Public health effects	Infrastructure & investment	Environmental impact	Price indices	Data collection method/technology used	Frequency of data collection	Size of data collection (geographical)	Size of data collection (number of sample units)	Data use
Europe																																
Calabrese, F, M Colonna, P Lovisolo, D Parata and C Ratti (2008) *Real-time urban monitoring using cell phones: a case study in Rome*. Accessed 28 October 2014. http://senseable.mit.edu/papers/pdf/2007_Calabrese_Colonna_Lovisolo_Parata_Ratti_senselab.pdf													x					x	x	x		x						LocHNES (localizing and handling network event systems), anonymous monitoring of cellular networks plus buses and taxis.	Real time example of every five minutes provided.	Rome. Total of 2,000 measurement points to cover eight areas.		Understanding urban dynamics, urban mobility, monitoring of vehicles and pedestrians. This is an exploratory investigation and gives an insight into how mobile data use can be used in an urban environment.
Hitchcock, G (2012) *National travel survey 2011 GPS pilot: summary analysis*. London: Department for Transport.														x				x	x			x						Report summarising the findings of the 2011 National Travel Survey GPS pilot survey and a comparison of its results to the main National Travel Survey.				
Hitchcock, G (2007) *Highways Agency trials GPS data for road management.*														x				x	x					x				The Highways Agency is trialling combining GPS data with data from its existing sources to provide 'real time' information to drivers on a 'beta' version of its traffic information map for drivers in England.				
Toledo-Moreo, R and MA Zamora-Izquierdo (2010) *Collision avoidance support in roads with lateral and longitudinal manoeuvre prediction by fusing GPS/IMU and digital maps*. Accessed 28 October 2014. www.um.es/gsit/research_lines/its/files/CollisionAvoidance.pdf										x				x									x	x	x	x		Investigation about predicting the movement of a vehicle via the use of GNSS technology to allow accurate prediction of the movement of a vehicle in a risky situation such as a collision.				
Beni, 2008. *Monitoring Conditions and Making Decisions: A GIS approach to managing traffic at the European Football Championship. David Beni, arx IT,* 2008. http://www.esri.com/news/arcuser/0708/footballtraffic.html																		x	x			x						AGIRE (GIS application)		Locality of Geneva		Monitoring traffic at the European Football Championships in order to make decisions on traffic management.
Wilson, RE (2008) *From inductance loops to vehicle trajectories*. University of Bristol.	x																	x	x			x						Single loops measures flow and occupancy, double loops measure vehicle velocity and length. Measurements are bundled into time averages (one minute is a typical unit) and communicated to the control office. Individual vehicle data (IVD) stores velocity, length and timing of individual vehicles before the time-average is applied.		Typically one inductance loop every 500m in UK/Western Europe.		Research undertaken outlines findings from study on M42 managed motorway to identify use of IVD – findings and traffic data available.
Malykhina, E (2005) *TomTom combines real-time traffic data with GPS navigation*. Accessed 28 October 2014. www.informationweek.com/tomtom-combines-real-time-traffic-data-with-gps-navigation/d/d-id/1061467?										x				x					x			x						GPS systems provider TomTom uses smart navigation software and advanced traffic information to inform drivers about traffic conditions in the Netherlands.	TomTom is able to refresh traffic data every three minutes and offer drivers up to five times more traffic updates by using multiple sources and techniques.	Netherlands		

	Digital data technology																	Network performance indicators										Summary information				
	Conventional								Emerging																							
Reference	Inductive loops	Infra-red	Radar	Manual counts	Ultrasonic detectors	Pneumatic tube	Video imaging	Piezo-electric cable	Weight in Motion (WiM)	In-vehicle comms system	IR beacon	Blue-tooth	GSM	GPS	Micro-wave	Laser	Fibre optic	Transport volume	Network reliability	Freight industry	Access to transport system	Travel patterns	Transport safety security	Public health effects	Infrastructure & investment	Environmental impact	Price indices	Data collection method/technology used	Frequency of data collection	Size of data collection (geographical)	Size of data collection (number of sample units)	Data use
Europe																																
Poole, G and GR Venter (2004) *Measuring accident scenes using laser scanning systems and the use of scan data in 3D simulation and animation*. University of Pretoria.																x						x	x	x				TRL are developing applications for 3D laser scanning technology in traffic accident investigation and reconstruction. The technology is time efficient.		Relevant to accident scenes only		Technology can be used for the spatial measurements of physical evidence at traffic accident scenes including vehicle positions, vehicle damage, tyre and other road markings, debris, road geometry, and surrounding environment. Provides time savings in the measurement of complex road traffic accidents.
USA																																
FHWA (2013a) Federal State Highway state and local GIS practices (current). Accessed February 2013. *www.gis.fhwa.dot.gov/default.asp*	x	x	x	x	x	x	x	x			x			x		x		x	x	x	x	x	x	x	x	x	x	Analysis of the use of GIS for safety decision making at the state and local level in the US, and discusses potential applications of GIS for improving safety in the highway network when used by the FHWA.				
FHWA (2013b) Freight management and operations - data sources related to freight transportation. Accessed February 2013. *http://ops.fhwa.dot.gov/freight/freight_analysis/data_sources/*	x	x	x			x	x	x	x	x		x		x						x								A list of resources which provide national road freight data.				
FHWA (2012) Operational performance measures: The Foundation for Performance-Based Management of Transportation Operations Programs. Accessed February 2013. *http://ops.fhwa.dot.gov/publications/fhwahop12018/fhwahop12018.pdf*																		x	x	x	x	x	x	x	x	x	x	Overview of how transportation networks can be made more efficient by measuring network performance against appropriately selected criteria.				
FHWA (2011) Urban congestion trends (by year 2011). Accessed February 2013. *http://ops.fhwa.dot.gov/publications/fhwahop12019/fhwahop12019.pdf*																		x	x	x	x	x	x	x	x	x	x	Discussion of improvements to transport operations and benefits yielded by them.				
FHWA (2005) *Archived data management systems – linking operations and planning data*. US: Federal Highways Administration.																		x	x	x	x	x	x	x	x	x	x	Investigation of five transportation agencies who have established Archived Data Management Systems (ADMS). The basics of setting up, likely challenges and potential benefits are presented with the aim providing guidance to agencies who are considering setting up their own ADMS.				
Mimbela, LEY and LA Klein (2000) *Summary of vehicle detection and surveillance technologies used in intelligent transportation systems*. Washington, DC: Federal Highway Administration, Intelligent Transportation Systems Joint Program Office.	x	x	x		x	x	x	x																				Contains none of this information – only a summary of surveillance mechanisms.				
Barcelo, J M Kuwahara and M Miska (2010) *Traffic data collection and its standardization.* New York: Springer.	x	x	x		x		x					x		x				x										Model validation				

	Digital data technology																	Network performance indicators										Summary information				
	Conventional								Emerging																							
Reference	Inductive loops	Infra-red	Radar	Manual counts	Ultrasonic detectors	Pneumatic tube	Video imaging	Piezo-electric cable	Weight in Motion (WIM)	In-vehicle comms system	IR beacon	Blue-tooth	GSM	GPS	Micro-wave	Laser	Fibre optic	Transport volume	Network reliability	Freight industry	Access to transport system	Travel patterns	Transport safety security	Public health effects	Infrastructure & investment	Environmental impact	Price indices	Data collection method/technology used	Frequency of data collection	Size of data collection (geographical)	Size of data collection (number of sample units)	Data use
USA																																
Yim, YBY and R Cayford (2001) *Investigation of vehicles as probes using global positioning system and cellular phone tracking, field operational test.* Berkeley28/10/2014 Institute of Transportation Studies, University of California.												x		x														Evaluation of in car GPS and cell phone tracking technology for use in vehicle probes.				
Zhao, Y (2000) Mobile phone location determination and its impact on intelligent transportation systems. *IEEE Transactions on Intelligent Transportation Systems 1*, no.1: 55-64.													x					x	x			x			x			Research and development on the technologies of locating the mobile (wireless) phone caller have been rapidly gaining momentum around the world. Once these technologies are mature enough to be deployed, they will have significant impact on automotive telematics and modern public transit systems.				
Tong, D, C Merry and B Coifman (2005) *Traffic information deriving using GPS probe vehicle data integrated with GIS. Ohio:* Center for Urban and Regional Analysis and Department of Geography. The Ohio State University.														x				x										Extracting transportation information using GPS receivers		DGPS receiver was used to collect probe vehicle data along several highways of interest in Columbus, Ohio.		The results of GPS data compared favourably with the corresponding loop detector data.
Wilson, C (2012) *Behaviour vs physical maps for advanced transportation applications.*	x						x			x				x														Investigation of the strengths, weaknesses and interrelationships between physical maps and behavioural maps.				
Abbas, R (2011) The social implications of location-based services: an observational study of users. *Journal of Location Based Services 5,* no.3/4: 156-181.														x														Study based from a social perspective investigating the impact of having an individuals movements digitally tracked continuously.				
Inrix (2013) Accessed February 2013. www.inrix.com.										x		x		x				x	x	x	x	x	x			x		Product brochure for INRIX presenting its capabilities in traffic and travel services.				
Overman, JH, S Tucker and M Sandidge (2011) *Transportation plan repository and archive.* Texas Transportation Institute.																		x	x	x	x	x	x	x	x	x	x	An overview of the development of a repository and archive for transportation planning document in Texas which allows users access to transportation plans and historic transportation decisions.				
Chou, EY and E Salari (2010) *A novel image database analysis system for maintenance of transportation facility - phase I.* University of Toledo.							x											x					x	x	x	x	x	Research project aimed at developing an image based system to allow transport agencies to economically and effectively manage road networks.				
Ingbar, E (2010) *A case study of enterprise historic resources information management in large transportation agencies*. Mineta Transportation Institute.														x				x	x	x	x	x	x	x	x	x	x	Investigation of how existing information systems used by Caltrans can be used for managing information on historic resources and how lessons learned during this investigation can be adopted by transportation agencies elsewhere.				
US DOT (2012) *Regional transportation systems management and operations, data collection and sharing.* US Department of Transportation. Accessed February 2013. www.plan4operations.dot.gov/data_coll.htm																		x	x	x	x	x	x	x	x	x	x	Overview of the data sharing systems as it relates transportation engineering. Information covered includes fundamentals of establishing and maintain a data sharing system as well as the benefits to be gained from operating such a system.				
Florida DOT (2001) *Innovative traffic data collection: an analysis of potential uses in Florida*. Florida Department of Transportation. Accessed February 2013. www.plan4operations.dot.gov/docs/wsdot.pdf	x									x				x				x	x									This report provides an analysis of a number of innovative methods for collecting traffic sensor data and their potential applications in florida. the main focus of this analysis focuses on the applications of these data collection methods on the Florida Interstate highway system.				

	Digital data technology																	Network performance indicators										Summary information				
	Conventional								Emerging																							
Reference	Inductive loops	Infra-red	Radar	Manual counts	Ultrasonic detectors	Pneumatic tube	Video imaging	Piezo-electric cable	Weight In Motion (WIM)	In-vehicle comms system	IR beacon	Blue-tooth	GSM	GPS	Micro-wave	Laser	Fibre optic	Transport volume	Network reliability	Freight industry	Access to transport system	Travel patterns	Transport safety security	Public health effects	Infrastructure & investment	Environmental impact	Price indices	Data collection method/technology used	Frequency of data collection	Size of data collection (geographical)	Size of data collection (number of sample units)	Data use
USA																																
Bremmer,D, KC Cotton, D Cotey, CE Prestrud and G Westby (2004) *Measuring congestion: learning from operational data*. Accessed 28 October 2014. www.wsdot.wa.gov/NR/rdonlyres/E8FBCE6A-BF80-4787-9AF7-8D1799EA0327/0/WSDOT_Measuring_Congestion.pdf	x						x											x	x	x	x	x	x	x	x	x	x	Report summarises how the Washington State DoTT (WSDOTT) uses operational data to assist in measuring congestion, evaluating capital and operational improvements, and communicating traveller information and system performance to the public. It is not intended as the definitive work on congestion measurement; rather, it describes wsdot's experience in learning more about congestion measurement.				
Virginia DoT (2013) *State environmental review process*. Accessed February 2013. www.virginiadot.org/projects/environmental-SERP-faq.asp														x				x	x		x	x				x		Virginia DoT has integrated GIS into its planning process. CEDAR is used to catalogue transportation and natural resource data for use in transportation geospatial applications.				
AASHTO (2013) *Transportation systems operations and management guidance*. American Association of State Highway and Transportation Officials. Accessed February 2013. www.aashtosomguidance.org.																		x	x	x	x	x	x	x	x	x	x	Not directly relevant - analysis of the agency capacity to use the data rather than the data/performance issue.				
White, S (2012) Determining the effectiveness of incorporating geographic information into vehicle performance algorithms. Master's thesis. Idaho State University.														x									x	x		x		The report discusses how incorporating geographical information on the journey affects existing vehicle performance algorithms.				

Appendix B: Comprehensive list of transport indicators

Table B.1 Overview of indicator sets

Ref	Title/ description	Country/ state	Organisation/ author	Short description/summary	Years provided/ frequency updated	Geograph-ical extent	Transport network	Data presentation	Link
TMIF2	*Transport monitoring indicator framework* (version 2) (TMIF2)	New Zealand	MoT	The Transport Monitoring Indicator Framework, version 2 (TMIF2), is the main source for transportation indicators in New Zealand. Published by the MoT, TMIF2 contains a large range of transport-sector indicators covering many types of land transport activity. The TMIF2 categorises indicators into sets, and contains a mix of both national and regional indicators.	Updated as new information available	New Zealand	All modes of transport - road, railway, air, sea transport	Website	www.transport.govt.nz/ourwork/tmif/
NZ Trans-port Agency	*NZ Transport Agency statement of intent 2012–2015* (SOI)	New Zealand	NZ Transport Agency	The statement of intent (SoI) sets out an approach and course of action for the next three years that will contribute to the delivery of the government's land transport objectives and wider transport vision. It includes performance measures and what is intended to be measured (and how) and details of what is expected to be accomplished. The SoI is a statutory compliance document.	Yearly	New Zealand	Road	Statement of Intent (report)	www.nzta.govt.nz/resources/statement-of-intent/2012-2015/soi-2012-2015.html
AUST	Austroads national performance indicators	Australia/ New Zealand	Austroads	Austroads' national performance indicators were developed following consultation with stakeholders including the road transport industry – and best represent the economic, social, safety and environmental performance of the road system and road authorities. Updated data is published each year to provide important time series information for the transport industry.	Updated yearly	State-by-state (incl New Zealand). All public roads	Road	Website: tables and graphs	http://algin.net/austroads/site/Index.asp?id=5

Ref	Title/ description	Country/ state	Organisation/ author	Short description/summary	Years provided/ frequency updated	Geograph-ical extent	Transport network	Data presentation	Link
VIC	Annual network performance monitoring bulletins	Australia/ Victoria	VicRoads	VicRoads has systematically collected, analysed and published traffic performance information on freeways and arterial roads in Melbourne since 1994. As part of the national Austroads programme, all metropolitan freeways and a 22% sample of arterial roads are monitored. The results are published annually in the Traffic monitor (performance monitoring information bulletin), showing the performance trends for average travel speed and delay by road type.	Updated yearly	Victoria/ Melbourne	Road, includes some PT and tram data	Bulletin with maps, graphs and commentary	www.vicroads.vic.gov.au/Home/Moreinfoandservices/RoadManagementAndDesign/RoadUseAndPerformance/NetworkPerformanceMonitoring.htm
TAC	*Performance measures for road networks: a survey of Canadian use*	Canada	Transportation Association of Canada	This report surveys Canadian provincial and territorial jurisdictions regarding current practices for performance measurement of road networks. A brief overview of the extensive literature available on the subject of performance measurement is provided. This report does not evaluate or recommend any one or set of performance measures but concludes by summarising areas of commonality between Canadian jurisdictions with regard to the use of performance management.	March 2006	Canadian provinces and territories	Road	Survey report	www.tac-atc.ca/english/resourcecentre/readingroom/pdf/perf-measures-0306.pdf
US NTS	US national transpor-tation statistics	USA	US Department of Transportation, Bureau of Statistics	National transportation statistics present statistics on the US transportation system, including its physical components, safety record, economic performance, the human and natural environment, and national security.	Updated quarterly	USA	All networks (including road, rail, air, water)	Report (tables)	www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/index.html
CAN MF	*Model framework for the assessment of the state, performance and management*	Canada	National Round Table on Sustainable Infrastructure (NRTSI), National Research	The model framework identifies the relevant performance objectives, assessment criteria, and indicators needed for the evaluation of the state and performance of core public infrastructure (CPI) at different levels of government. The framework enables the assessment of the performance of the transportation infrastructure (roads, bridges and public transit) as well as	May 2009	Canada – all levels of government	Roads, public transit and related infrastructure	Report	www.nrtsi.ca/documents/Framework.E.pdf

Ref	Title/ description	Country/ state	Organisation/ author	Short description/summary	Years provided/ frequency updated	Geograph-ical extent	Transport network	Data presentation	Link
	of Canada's core public infra-structure		Council Canada (NRC)	health/environment infrastructure (eg water, wastewater) with regard to seven key objectives: public safety, public health, mobility, environmental quality, social equity, public security and the economy.					
ASEAN-Japan	ASEAN-Japan transport indicators	South-East Asia and Japan	Association of South East Asian Nations (ASEAN) – Japan Transport Partnership	Presents and compares transport indicators (including road transport) for Japan, Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam. Includes definitions and data sources.	Annually	ASEAN and Japan	Roads	Website tables	www.ajtpweb.org/statistics
US FHA	Highway statistics series	USA	US Department of Transportation, FHA	The Highway statistics series consists of annual reports containing analysed statistical information on motor fuel, motor vehicle registrations, driver licenses, highway user taxation, highway mileage, travel, and highway finance. The information is presented in tables as well as selected charts. It has been published annually since 1945.	Annually	USA	Highway network	Excel tables on website	www.fhwa.dot.gov/policyinformation/statistics/2011/
DfT GB	Transport statistics Great Britain (TSGB)	UK	Department for Transport (DfT)	*Transport statistics* Great Britain is DfT's main statistical compendium publication. It describes the major statistical trends in the British transport sector, and is normally published in the final months of each calendar year.	Annually	Great Britain	All transport	Report (with associated tables)	www.gov.uk/government/publications/transport-statistics-great-britain-2012
EC	European transport statistics databases	Europe	European Commission: Eurostat	A database of transport statistics for Europe. For road transport, statics are provided for road transport infrastructure, vehicle stock and registration, road transport - enterprises, economic performances and employment, road traffic, road transport measures - passengers, road freight and crashes.	Annually	Europe	All transport	Web portal	http://epp.eurostat.ec.europa.eu/portal/page/portal/transport/introduction

Ref	Title/ description	Country/ state	Organisation/ author	Short description/summary	Years provided/ frequency updated	Geograph-ical extent	Transport network	Data presentation	Link
NCFRP	National freight performance measures	USA	National Cooperative Freight Research Program (NCFRP)	This report presents a comprehensive, objective and consistent set of measures to gauge the performance of the freight transportation system. The measures are presented in the form of a freight system report card, which reports information in three formats, each increasingly detailed, to serve the needs of a wide variety of users.	2011	USA	Freight	Report	http://onlinepubs.trb.org/onlinepubs/ncfrp/ncfrp_rpt_010.pdf

Table B.2 Contents of indicator sets

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
Transport volume	Distance travelled	Road vehicle kilometres travelled (VKT)	X			X	X	X			X	X	X	
		Road VKT by vehicle type and/or engine size	X			X					X	X	X	
		Road VKT per lane-km						X						
		Road VKT per network kilometre		X										
		Road VKT by road type	X								X	X	X	
		Road VKT by fuel type	X											
		Total person-km travelled	X											
	Current vehicle fleet	Total vehicle fleet numbers	X					X		X				
		Road fleet by fuel type	X											
		Road fleet by engine size and/or vehicle type (by one or more vehicle type)	X			X		X		X		X		
		Road fleet by category (incl. age, motor energy, alternative motor energy, power, load capacity, number of seats, kind of transport)											X	
		Average age of the road fleet (by one or more vehicle type)	X					X						

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
	New vehicle fleet	Total number of first registrations of road vehicles	X											
		New and used passenger car sales and leases						X						
		Sales of hybrid vehicles						X						
		Sales, market shares and sales-weighed fuel economies of vehicles						X						
	Occupancy	Mean vehicle occupancy (people/km) - by one or more vehicle type	X											
		Distance travelled in single occupant vehicles in major urban areas on weekdays	X											
		Lane occupancy rate (persons/lane/h)			X	X								
		Freight lane occupancy (tonnes/lane/h)				X								
		Car occupancy (people/car)			X	X								
		System travel density trends (weighted ave AADT per lane)									X			
	Other modes - walking/ cycling	Distance cycled	X											
		Distance cycled per person	X											
		Bicycle volumes along specified routes (counts)				X								
		Time spent walking	X											
		Time spent walking per person	X											
		Distance walked or cycled by residents of main and secondary urban areas	X											
		Number of walking and cycling trip legs	X											
	Other modes – public/ passenger transport	PT number of passengers or boardings (total or by mode and/or service type)	X	X		X			X	X		X		
		Road passenger-kilometre (by mode or service type)								X		X		
		Total operational mileage of public buses								X				
		Volume of passenger transport relative to GDP											X	

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
		Modal split of passenger transport											X	
Network reliability	All	Network congestion	X*		X									
		Annual highway congestion cost						X						
		Reliability of travel time (Congestion Index)	X#					X						
		Average reliability of journey times for key corridors	X*		X									
		Percentage variability of travel time	X#		X	X								
		Average journey times for key corridors	X*											
		Average travel time per 10km			X									
		Productivity (speed and flow)			X									
		Average delay (min/km)				X								
		Minutes delay per km during AM peak in Auckland		X										
		Percent delay (trucks)					X							
		Annual person-hours of highway traffic delay per person						X						
		Peak spreading (peak period duration - hours)				X								
		Actual travel volume/design capacity ratio (congestion level)							X					
		Number of restricted/closed lanes							X					
		Number of load restricted roads							X					
		Actual/average travel speed			X	X	X		X					
		Nominal travel speed			X				X					
		Vehicle speeds on non-built up roads by road and vehicle type										X		
		Vehicle speeds on built-up roads by speed limit and vehicle type										X		
		Average vehicle speeds (flow-weighted) during the weekday morning peak on locally managed 'A' roads										X		
		Variation from posted speed limit			X									

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
Freight and the transport industry	Freight measures	Freight tonne-km growth compared to gross domestic product (GDP) growth (by mode)	X											
		Domestic freight tonne-km by mode	X					X		X				
		Average load (tonnes) of heavy vehicles	X	X									X	
		Average daily measured weight of freight vehicles (tonnes)												
		Average load factor of heavy vehicles	X*											
		Percentage of heavy vehicle empty running	X*										X	
		Freight road volume (tonnes/carriageway/hour)				X								
		Freight weight transported - total and/or by mode or mode-share (eg thousand ton)								X		X	X	
		Goods lifted and moved by type and weight of vehicle										X		
		Average length of haul by type of vehicle										X		
		Road freight by type of goods											X	
		Volume of freight transport relative to GDP											X	X
		Freight demand - truck freight forecasts												X
		Freight demand - Transportation Services Index												X
		Freight efficiency - NHS travel speed urban												X
		Freight efficiency - NHS travel speed rural												X
		Freight efficiency – trend line of top 10 highway freight bottlenecks												X
		Freight efficiency - composite class I RR speeds												X
		Freight efficiency - cost of logistic as percent GDP												X
	Transport sector and economy	Employment in the transport sector by group	X					X				X	X	
		Number of trucking companies												
		Number of trucking companies								X				

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
		Number of domestic forwarders								X				
		Number of warehouse companies								X				
		Number of fixed route bus operators								X				
		GDP by industry - transport and storage	X					X						
		GDP: percentage contribution of transport and storage industry	X					X						
		GDP: annual change in the percentage contribution of transport and storage industry	X											
Access to the transport system	All	Percentage of household expenditure on transport	X											
		Access to essential services	X*									X		
		Percentage of the population who can get to key locations door-to-door by PT, walking and cycling	X*											
		Percentage of households with access to a motor vehicle	X									X		
		Number of households with access to nil, one, two, or three motor vehicles	X									X		
		Vehicle ownership per capita	X											
		Percentage of households with a bicycle in working order	X											
		Travel perceptions for walking	X											
		Travel perceptions for cycling	X											
		Travel perceptions for PT (general)	X											
		Travel perceptions for car	X											
		Travel perceptions for bus	X											
		Travel perceptions for total mobility services	X											
		Travel perceptions for bus by territorial authority	X											
		User satisfaction (road network)			X									
		Percentage of the population living within 500m of a bus route	X											

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
Access to the transport sytem	All	Distance to public transit service							X					
		Public transit: relative delay rate							X					
		Public transit: directness of route							X					
		Public transit: on-time performance							X					
		Public transit: headway/frequency of service							X					
		Public transit: bus stop spacing							X					
		Public transit: maximum occupancy							X					
		Public transit: access to service (distance, affordability)							X					
		Total mobility boardings per year	X											
		Fully accessible buses and trains, as a percentage of the total fleet	X											
		Percentage of fully accessible bus stops and train stations	X											
		Number of wheelchair-accessible taxis	X											
		Availability of accessible information about PT services	X											
		Older and disabled concessionary travel passes, bus journeys and bus journeys per pas										X		
		Percentage of survey respondents that consider PT as a good option for taking all or their work or study trips in Auckland		X										
		Farebox recovery rates	X											
		Percent of population within 1km of surfaced road							X					
Travel patterns	All	Modal shifts in schools with travel plans	X											
		Mode shifts in total trip legs	X											
		PT mode share of all trip legs	X											
		Ratio of PT trip legs to driver trip legs	X											
		Walking and cycling and other active modes' share of total	X											

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
		trips by residents of urban areas												
		Mode share for journey to work	X			X		X						
		Mode share for journey to school	X											
		Percentage of road-based short trips of less than 5km by bicycle	X											
		Percentage of short trips of less than 2km on foot	X											
		Change in mode share of workplace travel	X											
		Kilometres travelled for workplace travel (all modes)	X											
		Trip duration for workplace travel	X									X		
		Average distance by mode										X		
		Average number of trips by purpose and main mode										X		
		Average distance travelled by purpose and main mode										X		
		Usual method of travel to work by region of residence and region of workplace										X		
		Annual mileage of 4-wheeled cars by type and trip purpose										X		
Transport safety and security	Crash numbers and rates	Number of crashes	X					X		X		X		
		Number of fatal crashes	X											
		Number of deaths	X							X			X	
		Number of injuries	X					X		X		X		
		Number of property damage only incidents					X	X						
		Number of occupant fatalities by vehicle type and non-occupant fatalities						X						
		Number of deaths on roads per 100,000 population	X		X									
		Number of deaths on roads per 100 million VKT	X	X	X		X	X	X		X			
		Number of reported road injuries per 100,000 population	X											
		Number of reported road injuries per 100 million VKT	X				X	X	X					

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
Transport safety and security	Crash numbers and rates	Serious injury crashes per 100,000 population			X									
		Serious injury crashes per 100 million VKT		X	X									
		Persons hospitalised per 100,000 population			X									
		Persons hospitalised per 100 million VKT			X									
		Truck injury and fatal crashes												X
		Crash rates per million VKT					X	X	X					
		Percent incidents involving trucks per 100 million VKT					X							
		Passenger casualty rates by mode									X			
	Contributing factors	Number of deaths on roads with alcohol as a contributing factor	X					X						
		Fatalities or serious injuries in crashes with alcohol/ drugs, per 100,000 population		X										
		Reported road crashes: breath tests performed on car drivers and motorcycle riders involved in injury crashes										X		
		Reported crashes and crash rates by road class and severity										X		
		Front and rear safety belt and child restraint wearing rates	X					X						
		Estimated number of lives saved by use of restraints												
		Unimpeded speeds on urban and open roads	X											
		Number of deaths on roads with speed as a contributing factor	X											
		% vehicles exceeding 100km/h and 50km/h limits		X										
		Cycle helmet use	X											
		Motorcycle helmet use						X						
		ACC entitlement claims on the motor vehicle account from motorcyclists		X										
		Fatal & serious injury crashes in head-on or run-off crashes		X										
		Number of young drivers killed or seriously injured per 100,000 15-24 year olds		X										

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
Transport safety and security		% new light vehicles with 5-star safety rating		X										
		Rail grade crossing incidents/crashes					X	X						X
	Costs	Social cost of crashes	X											
		Social cost of serious casualty crashes per 100,000 population			X									
		Social cost of serious casualty crashes per 100 million VKT			X									
		Annual crash costs							X					
	Other measures	Perceptions of personal security while using the transport system	X											
		Personal security incidents while using the transport system	X											
		Number of resolved road closures with a duration of 12 hours or longer		X										
		Resilience of the transport system	X											
		Security of the transport system	X											
		Total number of transport-related occupational health incidents (long term and short term)	X					X						
Public health effects of transport	Air pollutants	N_2O concentrations	X											
		Total emissions of carbon monoxide, N_2O, VOCs, PM, SO_x etc.						X	X					X
		Vehicle emission rates per vehicle by type (one or more type specified)						X				X		
		Vehicle emissions per commuter							X					
		Auckland light vehicle emissions (CO, NO, HC, smoke)	X											
		Freight-related greenhouse emissions												X
		Air pollution trends in selected metropolitan areas						X						
	Noise	Highway noise barrier construction						X						

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
		Noise: actual dBa vs. acceptable level							X					
		Vehicle noise (dBa vs time)							X					
Infra-structure and environ-ment	Length	Length of road by functional class and road type (sealed and unsealed)	X					X		X	X	X	X	
		Lane length (including by functional system)									X			
		Length of tolled roads									X			
		Length of cycle path												
		Length of foot path												
	Quality measures	Road quality (SH and local roads/sealed and unsealed)	X					X						
		Cycle path quality	XX											
		Foot path quality	XX											
		Bus stop quality	X											
		Smooth travel exposure (4.2 IRI and 5.3 IRI)	X											
		Smooth travel exposure (4.2 IRI and 5.3 IRI) Nation Building Network			X									
		Smooth ride - % of travel on smooth roads (local roads;SHs)			X									
		International roughness index					X		X					
		Riding comfort indices (various indices)					X							
		Surface distress index												
		Surface condition of the sealed network (local roads; SHs)		X										
		Structural adequacy index					X		X					
		Pavement condition index					X							
		Pavement condition												X
		Pavement integrity of the sealed network (local roads; SHs)		X										
		Bridge condition					X	X						X
		Condition of NHS intermodal connectors												X

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
Infra-structure and environ-ment		Condition rating of assets							X					
		Skid resistance							X					
		Rut depth							X					
	Quality measures	Comprehensibility of markings, signs and messages							X					
		Protection against climate change impacts							X					
		Protection against deliberate/vandalism acts							X					
		Length of present serviceability rating (pavement condition) and measured pavement roughness, all systems									X			
	Expenditure and construction	Expenditure on infrastructure and services	X					X				X		
		Return on construction expenditure (BCR)			X		X		X					
		Net present value (measure of cost effectiveness)					X							
		Cost effectiveness of programmes							X					
		Estimated investment in national highways versus amount necessary to sustain conditions												X
		Cost of renewal of the network excluding emergency reinstatement (cents per vehicle km travelled) (local roads; SHs)		X										
		Cost of renewals (excluding emergency reinstatement) per network lane km (local roads; SHs)		X										
		Cost of emergency reinstatement (local roads)		X										
		Cost of maintaining and operating the network (excluding emergency work) per network lane km) (local roads; SHs)		X										
		Cost of maintaining and operating the network excluding emergency reinstatement (cents per vehicle kms travelled) (local roads; SHs)		X										
		Kilometres of new footpaths, cycle lanes and cycle paths		X										
		Length of bridge replacements (lane metres) (local roads; SHs)		X										

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
		% of sealed network resurfaced (based on road length) (local roads; SHs)		X										
		% of network rehabilitated (based on road length in lane km) (local roads; SHs)		X										
		% of unsealed network metalled (based on road length in centreline km) (local roads)		X										
		Fare revenue as a $ of total expenditure		X										
		PT boardings per NLTF $ invested on PT services		X										
		Use of recycled materials							X					
		Materials consumption							X					
Environ-mental impact of transport	Emissions	Tonnes of CO_2 emissions from domestic transport	X									X		
		Grams of CO_2 per km driven for new vehicles entering the light fleet	X											
		Tonnes of CO_2 emitted from domestic transport per vehicle km driven	X											
		Tonnes of CO_2 emitted from domestic transport per tonne-km	X											
		Tonnes of CO_2 emitted from domestic transport per person-km	X											
	Energy consumption	Total emissions of methane (CH_4) and nitrous oxide (N_2O)	X*											
		Vehicle emissions							X					
		Greenhouse gas emissions by transport mode										X		
		Energy consumption by the transportation sector	X					X	X					
		Energy use (PJ) per VKT by domestic transport	X											
		Energy use (PJ) per tonne-km by domestic transport	X											
		Energy use (PJ) per person-km travelled by domestic transport	X											

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
		Energy intensity of passenger modes						X						
		Energy intensity of passenger cars, other 2-axle 4-tyre vehicles and motorcycles												
		Energy consumption by transport mode and fuel type										X		
	Fuel consumption and efficiency	Motor fuel use (by type of fuel, road type and/or vehicle type)						X			X	X		
		Average diesel consumption per 100 VKT		X										
		Average petrol consumption per 100 VKT		X										
		Estimated consumption of alternative and replacement fuels for highway vehicles						X						
		Average fuel efficiency of passenger cars and light trucks						X						
		Annual wasted fuel due to congestion						X						
		Annual wasted fuel per person						X						
		Average new car fuel consumption						X						
	Other measures	Motor vehicles scrapped						X				X		
Transport related prices	**All**	Consumer price index - transport	X									X		
		Consumer price index - road passenger transport	X											
		Producers price index (output) - road freight transport	X					X						
		Retail prices index: transport components										X		
		Construction price index										X		
		Road construction tender price index	X											
		Transport and storage labour price index	X									X		
		Regular petrol pump prices												
		Diesel pump prices	X					X				X		
		International oil prices	X											

Category	Sub-category	Indicator	TMIF2	NZ Transport Agency	AUST	VIC	TAC	US NTS	CAN MF	ASEAN-JP	US FHA	DfT GB	EC	NCFRP
		Affordability of petrol				X								
		Price trends of gasoline vs. other consumer goods and services						X						
		Road user charges prices	X											
		Fuel and vehicle excise duty										X		
		Personal consumption expenditures on transportation by subcategory						X				X		
		Average cost of owning and operating an automobile						X	X					
		Average cost per vehicle-km or per tonnes-km							X					
		Average freight revenue per ton-mile						X						
		Average passenger fares						X						
		Local bus fares index by metropolitan area status										X		
		Average passenger revenue per passenger-mile						X						
GDP and population	All	GDP	X											
		Population	X			X								
Total number of indicators			94	32	22	16	17	55	40	15	10	44	14	16

Notes:

(a) RED indicator sets come from a research report, rather than an annual monitoring bulletin

(b) 'per capita' measures have been ignored (as these are easily calculated)

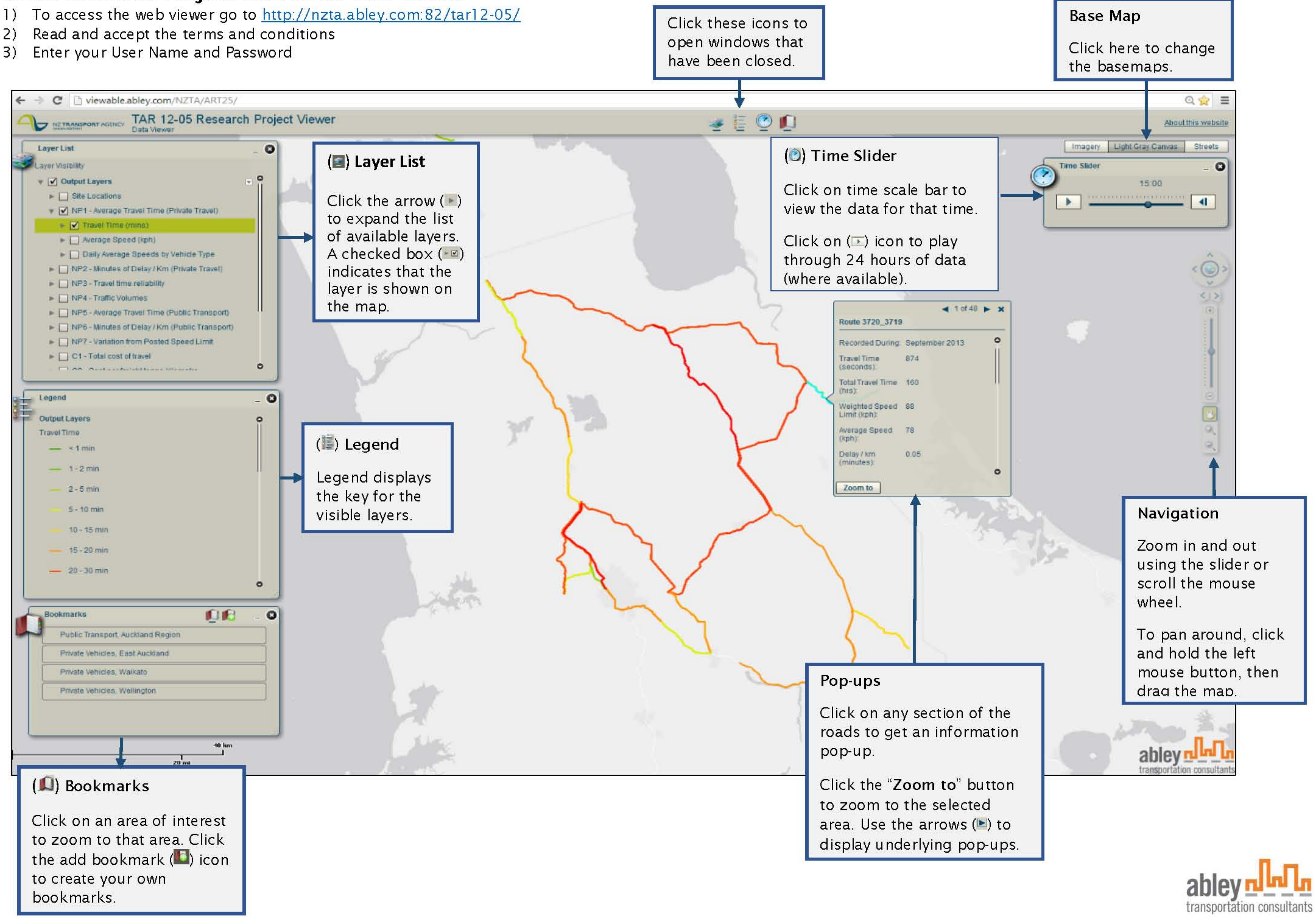
(c) Indicators for non-road transport modes have been ignored.

(d) * Data not available/collected; # Partial data only.

Appendix C: GIS web viewer user guide

NZTA Research Project TAR 12-05 Web Viewer

1) To access the web viewer go to http://nzta.abley.com:82/tar12-05/
2) Read and accept the terms and conditions
3) Enter your User Name and Password



Appendix D: Risk register

Activity	Steering Group Meeting/Risk Workshop	**Analyst Name(s)**	Sara Clarke (URS), Dave Smith (Abley), Dale Harris (Abley)
Project	TAR12-05 Research Project - Using Digital Data to Assess Performance of SH Network	**Reviewers Name(s)**	Sara Clarke (URS)
Date	6-Dec-13	**Sources of Information**	Risk Assessment Workshop discussions with Steering Group (27/11/13)

No.	Risk	Description	Consequence		Likelihood		Score = C x L[1]	Mitigation Actions	Rank
			Description	Rating (C)	Description	Rating (L)			
PROCUREMENT/THIRD PARTY ENGAGEMENT RISKS									
a	Frequency of data feeds and model updates	If the frequency of data feeds from third party providers does not match New Zealand Transport Agency reporting or planning timetables, the model will not provide timely information.	Minor	10	Unlikely	2	20	Frequency of data feeds to be specified in contract but flexibility can be maintained through short term contracts and/or variation clauses.	11=
b	Timeliness of data supply	If data supply is delayed, model outputs may not meet the expected timetable.	Minor	10	Likely	4	40	Early engagement with data suppliers and agreement of clear expectations enforced through contract.	9=
c	Data costs	If the costs of the data are too high, less data can be purchased and fewer indicators can be modelled. Uncertainty over the expected expenditure on data may jeopardise approval for the business case.	Major	70	Possible	3	210	Early engagement with suppliers, short term contracts initially, and undertake analysis to prioritise the value associated with each third party dataset. Encourage competition in the marketplace.	1=
DATA MANAGEMENT ISSUES									
d	Incomplete datasets	Gaps in data due to geographic coverage and reliability will lead to gaps or errors in the reporting of indicators.	Minor	10	Likely	4	40	Coverage likely to increase for BT and limited coverage sufficient for PT. Minimum service standards to be incorporated into contracts to cover reliability issues.	9=
e	New Zealand Transport Agency data storage and processing capacity	New Zealand Transport Agency may not be able to store and/or process the volume of data collected.	Minor	10	Unlikely	2	20	Use smart and efficient system design. Potential to contract out services for data processing and archiving.	11=
f	Intellectual Property	The IP rights of third party suppliers, particularly in relation to privacy and commercial sensitivity, may limit New Zealand Transport Agency's use of their data.	Major	70	Possible	3	210	Early engagement with suppliers and clear contract terms.	1=
g	Privacy	There could be a perceived privacy breach or conflict with the enforcement arm of New Zealand Transport Agency.	Major	70	Possible	3	210	Establish clear guidelines, prepare Memorandum of Understanding to mitigate privacy concerns. Investigate potential to contract out services to third party to manage data privacy. Engagement between industry groups and very senior New Zealand Transport Agency management could assist in alleviating privacy concerns.	1=
MODEL INPUTS AND OUTPUTS									
h	Potential for indicators to change	As the New Zealand Transport Agency indicator programme is still being developed, new indicators could be developed with different data or processing requirements.	Insignificant	1	Likely	4	4	New or altered indicators are tested to see if they can be measured by current or emerging datasets, prior to being rolled out across the New Zealand Transport Agency. Short-term data contracts and provisions for variations will provide flexibility if data requirements change.	14=
i	Extent of PT data	Limited PT data constrains the geographic coverage and range of indicators that can be modelled.	Insignificant	1	Likely	4	4	No mitigation required - risk acceptable.	14=
j	Extent of Bluetooth coverage	The currently limited extent of BT geographic coverage will constrain the value that can be delivered through the model.	Major	70	Unlikely	2	140	Ongoing engagement with BT data suppliers to understand growth in detector network and regular analysis to quantify match rates from detectors. Strategic focus within New Zealand Transport Agency to roll out BT deployment and investment.	5=
k	GPS data sample sizes and sources	The sample size and fleet representation of GPS data means that this data is not representative.	Medium	40	Unlikely	2	80	Ongoing engagement with data suppliers and regular analysis of raw data to understand changing trends (for example, sample rates and fleet composition over time). Statistical factors applied to datasets and analysis can help account for bias within the data. Undertake significance testing.	8
l	Lack of people throughput data	Current commercially available data does not support a measure of people throughput.	Insignificant	1	Almost Certain	5	5	Keep abreast of emerging technologies, including mobile opt-in applications and integrated PT ticketing.	13
m	Currency and quality of road centreline data	The centreline on which the model is based is updated annually so is not 'live' and there are quality and completeness issues with underlying attribute data.	Medium	40	Likely	4	160	Implement more regular updates. Develop a methodology to provide feedback on errors and upgrades identified during processing of data. New Zealand Transport Agency to put more emphasis on this as their reliance on the centreline increases.	4

DELIVERY OF PROPOSED MODEL									
n	Synergy with other New Zealand Transport Agency workstreams	If the model does not integrate with other New Zealand Transport Agency initiatives, the value of the data will not be realised.	Major	70	Unlikely	2	**140**	Ongoing engagement and communication within New Zealand Transport Agency, and internal promotion of the tool within the New Zealand Transport Agency to increase awareness.	5=
o	Integration of New Zealand Transport Agency geospatial data	If the model does not look like and perform similar to the other geospatial tools in the New Zealand Transport Agency, it will not be used.	Medium	40	Possible	3	**120**	Tool has been developed using the CAS centreline which is already used for a number of other purposes. Continue to look for opportunities for synergies.	7
Exceptions Statement									

Appendix E: Glossary

AADT	annual average daily traffic
AAWT	annual average weekday traffic
CAS	crash analysis system
CAU	census area unit
CCTV	closed circuit television
CO	carbon monoxide
CoF	certificate of fitness
CSV	comma-separated values
DEM	digital elevation model
ECan	Environment Canterbury
EEM	NZ Transport Agency *Economic evaluation manual*
FHA	Federal Highway Administration
GIS	geographic information system
GNSS	global navigation satellite system
GPS	global positioning system
GSM	global system for mobile communications
GWRC	Greater Wellington Regional Council
HGV	heavy commercial vehicle
IP	intellectual property
IPENZ	Institute of Professional Engineers New Zealand
ITS	intelligent transport systems
JTOC	joint traffic operation centre
KAT	KiwiRAP analysis tool
LGV	light commercial vehicle
MGV	medium commercial vehicle
MoT	Ministry of Transport
N_2O	nitrous oxides
PM	particulate matter
PT	public transport
RPS	road protection score
RUC	road user charges

SoI statement of intent (referring in particular to the Transport Agency's *Statement of intent 2012–2015)*

SH state highway

TDW transport data warehouse

TMIF Ministry of Transport's *Transport monitoring indicator framework*

TREIS traffic road event information system

Uid unique identifier

UMTS universal mobile telecommunications system

UTC urban traffic control

VKT vehicle kilometres travelled

VMS variable messaging sign(s)

VOC volatile organic compound

WiM weigh-in-motion

WoF warrant of fitness

WRC Wellington Regional Council