Accurate and affordable location technology for New Zealand November 2013

D Barnston, Opus International Consultants, Whangarei
R Brill, Opus International Consultants, Whangarei
A Harding, Opus International Consultants, Lower Hutt
NJ Jamieson, Opus International Consultants, Lower Hutt
M Ladd, Opus International Consultants, Auckland
N Stillwell, Opus International Consultants, Napier

NZ Transport Agency research report 535
Contracted research organisation – Opus International Consultants

ISBN 978-0-478-40784-6 (electronic)
ISSN 1173-3764 (electronic)

NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

NZ Transport Agency (2013) Accurate and affordable location technology for New Zealand. *NZ Transport Agency research report 535.* 71pp.

Opus International Consultants was contracted by the NZ Transport Agency in 2012 to carry out this research.

Keywords: location technology, geographic information system(s) (GIS), global navigation satellite system(s) (GNSS), global positioning system(s) (GPS), positioning

An important note for the reader

Acknowledgements

We would like to thank those who have acted as Steering Group members for this project, including Philip Blagdon and Ben White of the New Zealand Transport Agency, Aaron Jordan from LINZ, Iain McGlinchy from the Ministry of Transport, and Sean Rainsford from Fulton Hogan. We would also like to thank those who have acted as peer reviewers for this technical report, Paul Denys from the University of Otago, and Tony Darby from the New Zealand Transport Agency (Auckland Motorway Alliance). Their help and advice has been much appreciated.

Contents

Executive summary

This research was undertaken as part of the 2012/2013 NZTA Research Programme, as one of the technology solutions research topics. The key research question was to understand how the measurement and sharing of more accurate roading locations could be made routine, readily available and affordable in New Zealand conditions.

The research provided an understanding of the location technology requirements of key providers to the NZ Transport Agency ('Transport Agency') and of the Transport Agency itself, a review and evaluation of location technologies suitable for use on the highway, and the outputs of an engagement process with the wider industry to understand lessons learnt from the implementation of location technology. Based on this, we formulated a set of conclusions and recommendations.

Key performance indicators (KPIs) were developed to better understand the location technology requirements of the Transport Agency and key stakeholders. This process revealed a preference for accurate, affordable technology that was easy to use. A recommendation arising from this exercise is to review the KPIs and requirements on a regular basis to ensure the needs of the industry continue to be met.

The literature and technology review highlighted the on-going development of location technology methods and applications. It is recommended that this report or elements of it are kept current and that regular updates are scheduled.

The evaluation process highlighted technology that showed the most potential for immediate wider use. This included mapping grade global navigation satellite systems (GNSS) and consumer grade GNSS augmented with mobile geographic information systems (GIS) and accurate aerial imagery. In-depth trials within a small number of provider organisations are recommended, to understand how these systems can be more widely used.

There are other future technologies that show great promise. These include GNSS augmented with Locata type ground-based constellations and other wireless networks in areas of low GNSS coverage, as well as the wider use of ground-based LiDAR surveys. It is recommended that these technologies are tracked, and that the potential to trial some of these in the near future, or to undertake a more in-depth review, be considered.

Engagement with the industry identified a number of elements that facilitate the successful implementation of location technology. These include the support of upper management, training on appropriate use, organisational guidelines, safety assessment for in-vehicle use, awareness of staff privacy and dedicated staff to manage the overall process. It is recommended that these findings are also updated in location technology guidelines in the future.

Little evidence was found in current Transport Agency manuals regarding the use and accuracy requirements of location technology. It is recommended that more specific guidelines and requirements are incorporated into upcoming manual updates and a certification system for location technology requirements is implemented. It is also recommended that once the Transport Agency has defined its requirements, the providers take responsibility for choosing the most appropriate technology for a given situation.

Abstract

A potential gap between available location technology and its use on the ground was identified in the New Zealand land transport sector. This research sought to bridge that gap and support the NZ Transport Agency's ('Transport Agency') goal to increase the use of appropriate location technology by its key providers. Consultation with these was undertaken to understand the requirements for location technology and any lessons learnt from previous implementations. A literature and technology review and evaluation identified suitably accurate and affordable location technologies for use in road asset management in New Zealand.

Mapping grade global navigation satellite systems (GNSS) and consumer grade GNSS combined with mobile geographic information systems and imagery were found to be the most appropriate options for immediate use. Other promising technologies include augmenting GNSS with ground-based networks like Locata or other wireless systems (Bluetooth, WiFi, ultra wide-band). There is also potential for the wider use of ground-based LiDAR for desktop surveys.

The use of these technologies requires clear guidance. It is recommended that current Transport Agency manuals are updated to include guidelines for the use of location technology, with clear accuracy requirements. This will assist providers in choosing the most appropriate location technology for a given situation.

1 Introduction

1.1 Objectives

The purpose of this research project, undertaken in 2013, was to assess the suitability of different types of location technology for use by the New Zealand Transport Agency ('Transport Agency'), its key providers and other operators in the wider New Zealand economy. This will allow the Transport Agency and other road controlling authorities to establish spending options and priorities.

The principal objectives of the research were:

1. To develop a guide to location technology through a comprehensive literature and industry review
2. To establish the requirements of the Transport Agency and key stakeholders through the development of location technology performance indicators, with a strong focus on accuracy and affordability
3. To evaluate and rank the different location technology elements against the performance indicators
4. To define a roadmap to enable the better use and implementation of location technology in the transport sector.

1.2 Background

There is currently a wide variety of organisations and individuals that make use of location technology in New Zealand. In a roading context, these stakeholders include:

- the Transport Agency
- territorial and regional councils
- transportation consultants and contractors
- public transport operators
- post, freight and courier companies
- vehicle rental companies
- tourism operators
- emergency services (police, fire service, ambulance and civil defence).

Each of these groups uses location technology to find and record locations of works and infrastructure, or to direct personnel to specific locations to install, repair, pickup, deliver, or attend crashes or incidents. Accordingly, the accuracy of spatial data is important, and becoming more so with the increasing reliance on this information for everyday use. However, roading-related location technology and location infrastructure services are not integrated across the transport supply chain, and the quality and coverage is not sufficient to supply consistently accurate data across New Zealand at all times.

In particular, within the New Zealand transport asset management sector, the Transport Agency expressed a requirement for location technology to be accurate to 3m or better, for 99% of the time, over the entire state highway roading network. A consumer grade global positioning system (GPS) is only accurate to around 5m–20m, and coverage and reception can be limited by the topography and atmospheric conditions. Differential GPS can improve the level of accuracy, but the industry has currently deemed this option too expensive to adopt. Survey quality instrumentation can deliver accuracy in the centimetre range, but is substantially more expensive. Other potentially cost-effective solutions are currently being investigated and developed, for example, mapping grade global navigation satellite systems (GNSS) with software to enable recording of assets.

During the initial project workshop, the Transport Agency requested that the emphasis for this research should be on the use of location technology by roading contractors and consultants rather than by other parts of the transport supply chain. Although the technology reviewed and evaluated in this document is relevant in other areas, our focus throughout the research was on this target group.

1.3 Need for the research

The need for the research was driven by a combination of:

1. Increasing reliance on location technology by road users in New Zealand to both accurately record locations along the road network, and to direct personnel to specific locations
2. Lack of integration of location technologies across the transport supply chain
3. A need to improve both the accuracy and coverage of location technology, both in terms of area and timing, at an affordable cost
4. A desire to increase the collection of location information, by Transport Agency providers, using absolute rather than relative location technologies.

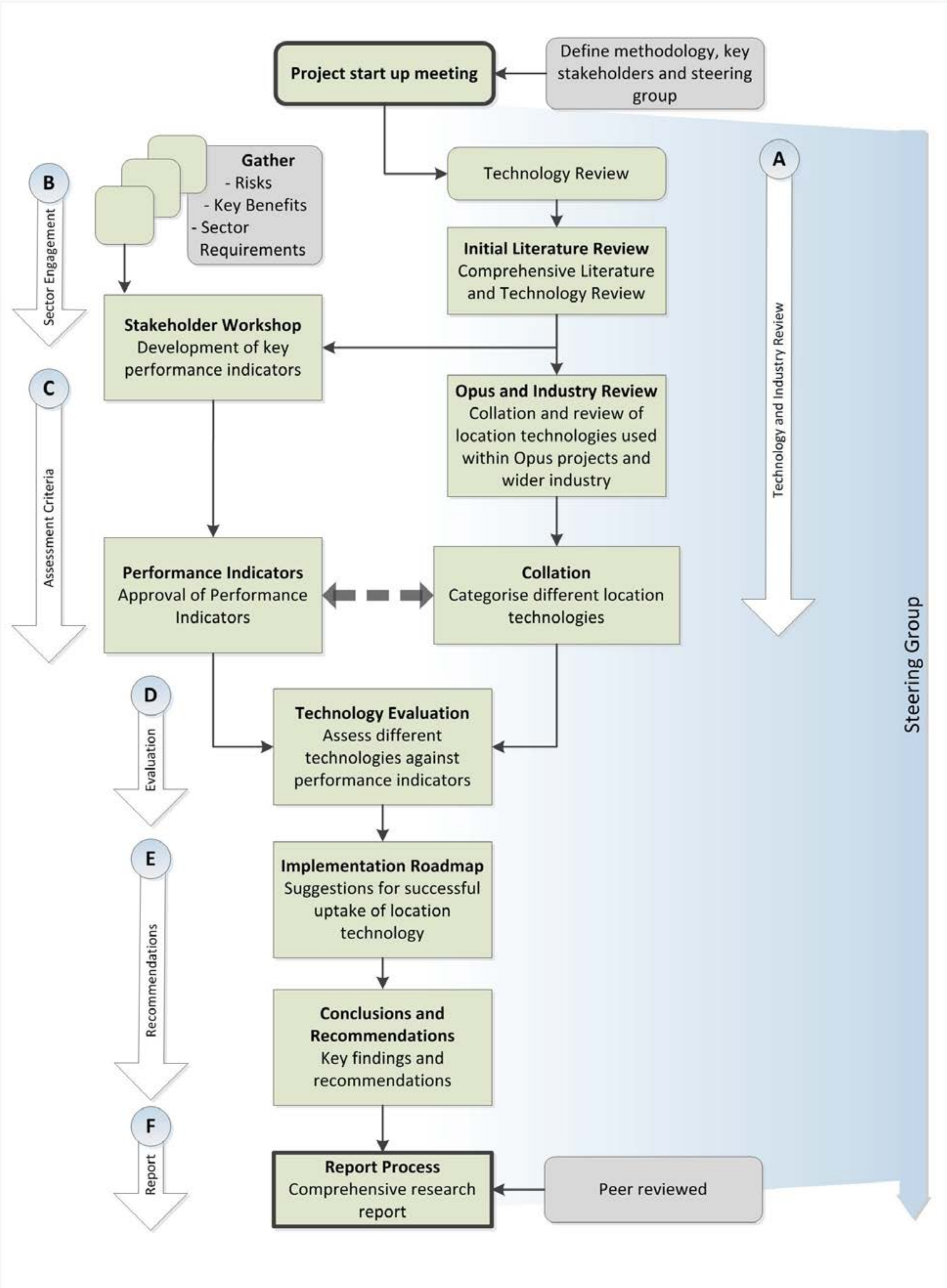
Critical to the ability to target this funding is the need to understand the attributes of the different location technologies available.

The broader spatial information industry was estimated to add $1.2 billion of value to New Zealand's economy in 2008. Improving the spatial data infrastructure was estimated to add a further $481 million of value-added output to the economy (ACIL Tasmin 2009). More informed and appropriate use of location technology will lead to more accurate and accessible spatial data, and to greater economic benefits.

1.4 Methodology

The field of location technology is an area of rapid advancement and the industry will benefit from periodic updates of the research as new technologies become available. Detailed documentation of the methodology used in this project will help streamline any updates. An overview of the methodology is given in figure 1.1 on the following page.

Figure 1.1 Summary of the research methodology



1.4.1 Technology and industry review (A)

The review of available location technologies involved four key steps:

1. *Initial literature review and stakeholder workshop.* Prior to the stakeholder workshop an initial high-level literature review was undertaken to determine a typology of the main nodes of technology to be investigated. The stakeholder workshop provided insight into the types of technologies and performance requirements of interest to the Transport Agency and the project steering group.
2. *Literature review.* A reference database of relevant academic and grey literature (informally published written material such as reports and brochures) was collated and different location technologies were reviewed.
3. *Industry review.* Parallel to the literature review, users of location technology within or related to the transport industry in New Zealand were sent an information request via email and some industry representatives were involved in a more detailed interview. This industry engagement provided local input to the technology review as the literature was predominantly sourced from overseas. The information request was sent to 52 organisations, with a response rate of about 50% with only 12 useful responses. The other responses provided very limited information which was not useable. The request sought information about the type of location technologies used by that organisation and also asked some questions around affordability, accuracy, ease of use and track record (the information request is provided in appendix A). The more detailed interviews were conducted with six stakeholder organisations (Fulton Hogan, Downer, Opus International Consultants Limited (Opus), RAMM Software Limited, the New Zealand Police and the New Zealand Fire Service) either in person or over the phone and focused on barriers and enablers for the implementation of location technology within an organisation (the interview schedule is provided in appendix B).

1.4.2 Sector engagement (B)

In addition to the industry interviews described above, a steering group workshop was held early in the project to clarify the objectives and define a set of performance indicators against which different technologies could be measured. The steering group was asked to provide feedback on some of the key modes of technology types under review during the workshop and the technology review. This ensured the research was grounded against the requirements of the key industries that would benefit from it. The workshop was attended by staff from Fulton Hogan, Land Information New Zealand (LINZ), the Ministry of Transport, the Transport Agency and Opus.

1.4.3 Assessment criteria (C)

A draft set of performance indicators was documented during the workshop, refined by the project team, and then sent back to the steering group for review (the performance indicators are detailed in full in chapter 3). This process resulted in a set of 12 performance indicators, each with parameters for determining a high, moderate or low classification.

1.4.4 Evaluation (D)

The evaluation process involved a number of steps to make the process as efficient as possible:

- Fatal flaw analysis – first, the long list of technologies identified in the review phase was shortened by eliminating technologies that were highly unlikely to be implemented on the highway network in New Zealand. In some instances a technology ranked highly but had one shortcoming rendering it unsuitable (a 'fatal flaw'). Based on the performance indicators, if a technology had very low accuracy and/or repeatability, was extremely expensive, or showed little future promise, it was discarded at this stage.
- Technology summary – the remaining technologies were then categorised into technology bundles or groups in preparation for the evaluation phase. Location technology is rapidly advancing, so for the longevity of this report it was deemed of little worth to specifically evaluate a certain make or brand of technology but rather the general category that technology falls within. For example, GNSS-enabled smartphones were reviewed as a group, rather than by particular brands, such as iPhones.
- Evaluation – the technology bundles were compared against each of the performance indicators and given a high, moderate, or low rating for each indicator. This evaluation was undertaken by a senior geospatial specialist and a surveyor, and was reviewed by another senior surveyor and a research scientist. The output of the evaluation was a classification of different technologies in terms of how effectively they match the requirements of the Transport Agency and key stakeholders.

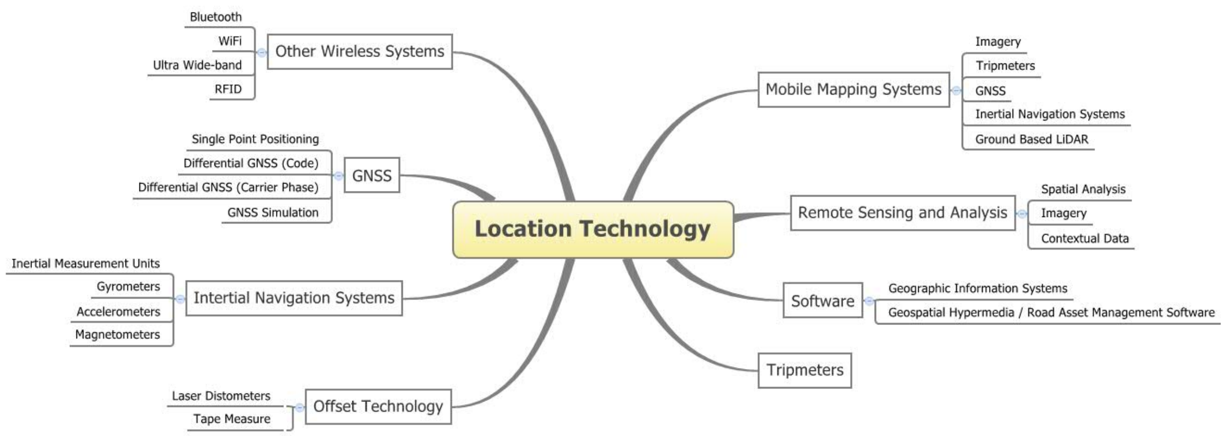
1.4.5 Recommendations (E)

The recommendations were based on the outputs of the evaluation process detailed above, a more in-depth discussion of some of the most suitable technologies, and relevant information obtained from the interviews with key stakeholders. This also includes an implementation roadmap that includes recommendations for enhancing the uptake of new technology based on the engagement process and literature review.

2 Literature and technology review

Technology to locate people or objects accurately on the earth's surface has been rapidly evolving over the last 30 to 40 years, primarily spurred on by the introduction of the GPS and advancements in computer science, particularly the rise in mobile computing technology. There are many ways to categorise location technology, partly because of its evolving nature but also due to the overlap and integration of many different technologies. The typology of location technology categories adopted for this review is outlined in figure 2.1. Other comprehensive reviews of location technology that provide good context for this research include: Zipf and Jöst (2012), Munoz et al (2009), Sahinoglu et al (2008), Samama (2008) and Bensky (2007).

Figure 2.1 Typology of location technologies reviewed



2.1 Global navigation satellite systems

GNSS has become a ubiquitous location technology with applications appearing on a wide range of devices in numerous industries. GNSS is an umbrella term for all satellite-based positioning systems, the most well-known of which is GPS, managed by the US government. There are numerous other systems ranging from fully operational to proposed, including the Russian global navigation satellite system (GLONASS); Galileo, being developed by the European Union; the Chinese Beidou or Compass system; the Indian regional navigational satellite system; (IRNSS), and the Japanese quasi-zenith satellite system (QZSS).

Each GNSS consists of an array of satellites orbiting the earth, which are accurately tracked by ground control stations spanning the globe. The original GPS design contains two ranging codes: the coarse/acquisition (C/A) code, which is freely available to the public; and the restricted precision (P) code, usually reserved for military use. Satellites transmit codes via a carrier frequency, either 1575.42 MHz (10.23 MHz × 154) called L1 or 1227.60 MHz (10.23 MHz × 120), called L2. The majority of civilian GPS devices track the C/A code on the L1 frequency, while more expensive survey grade GPS devices are also capable of tracking the L2 frequency (Uren and Price 2010). Each frequency has specific capabilities, eg the L1 frequency includes the C/A code that allows tracking of the L1 carrier phase; the L2 frequency has only the P(Y) code (protected), and consequently the L2 carrier phase cannot be tracked directly. There are also advantages in being able to track multiple frequencies from the same satellite.

GNSS positioning is based on ground-based receivers (combinations of hardware and software) that track the radio signals of the numerous satellites orbiting the earth, using accurate clock technology and the measurement of satellite to receiver distances to derive a location. To provide clarity to the following discussion, GNSS devices have been grouped into three basic categories:

- Consumer grade – devices that are typically cheap, easy to use and generally lower accuracy.
- Mapping grade – devices that generally have higher quality hardware and firmware, are designed for professional mapping use, and make use of more advanced positioning techniques. They generally have better accuracy and precision than consumer grade devices.
- Survey grade – these are at the top end of the accuracy spectrum and normally have very high quality hardware and firmware and use the most accurate positioning systems. They are designed for use by professional surveyors.

It is impossible to clearly define these categories because as new devices and technologies become available the boundaries between them become blurred and some devices will have characteristics from more than one category. Nevertheless it is a useful tool for general discussion.

In addition to the classification above, the GPS system is undergoing a programme of modernisation with modern GPS satellites having capability to broadcast a new range of codes and signals. While the timeframes are dependent on the replacement of the older satellite fleet, the US government web site http://gps.gov contains a clear summary of the proposed changes and outlines some expected timeframes. Although the benefits of this future technology have yet to be thoroughly researched and published, a summary of the proposed changes from the GPS.gov website are as follows.

Table 2.1 GPS signal changes and timeframes

New signal name	Brief description	Expected availability:
L2C	Enables quicker and more accurate position resolution – particularly for professional users with dual frequency systems.	Around 2018 on 24 satellites
L5	L5 is the third civilian GPS signal, higher powered and with greater bandwidth. Through a technique called tri-laning, the use of three GPS frequencies may enable sub-meter accuracy without augmentation.	Around 2021 on 24 satellites
L1C	Full operational date for this signal is a long way in the future but it is intended to enhance interoperability between GPS and other satellite navigation systems	Around 2026 on 24 satellites

The new signals are expected to increase the accuracy and performance of GPS in environments such as urban canyons and under vegetative canopy where positioning is currently unavailable or subject to significant errors (Mullenix et al 2009). The advent of L5 in particular may bring down the cost of high-accuracy units dramatically so that their benefits will be available to wider application (Gakstatter 2010).

The implications of GPS modernisation in the New Zealand context is still a matter for conjecture with little solid research available on the timings. Expecting reliable benefits from any of the signals before most of the 24 satellites are operationally broadcasting the new signals is optimistic as New Zealand is unlikely to be a high-priority coverage area. In order to utilise the new signals and codes GNSS receivers will need to be capable of receiving, interpreting and processing them. As the signals become available it is likely that new hardware will allow for increased positioning accuracy. As new hardware becomes available further research will be required to confirm the accuracies in the New Zealand environment.

Some of the examples outlined in this section are partially bundled because GNSS technology is incorporated into other devices (for example, tablet PC, ruggedised device) or devices that have software or hardware features that make them suitable for capturing road assets. There are numerous devices that fall within each of the positioning types but specific devices are not evaluated because of the rapid changes in the devices available. Rather, specific applications of the types of devices are considered for their use in a transport asset management in a general sense.

2.1.1 Issues affecting coverage and precision

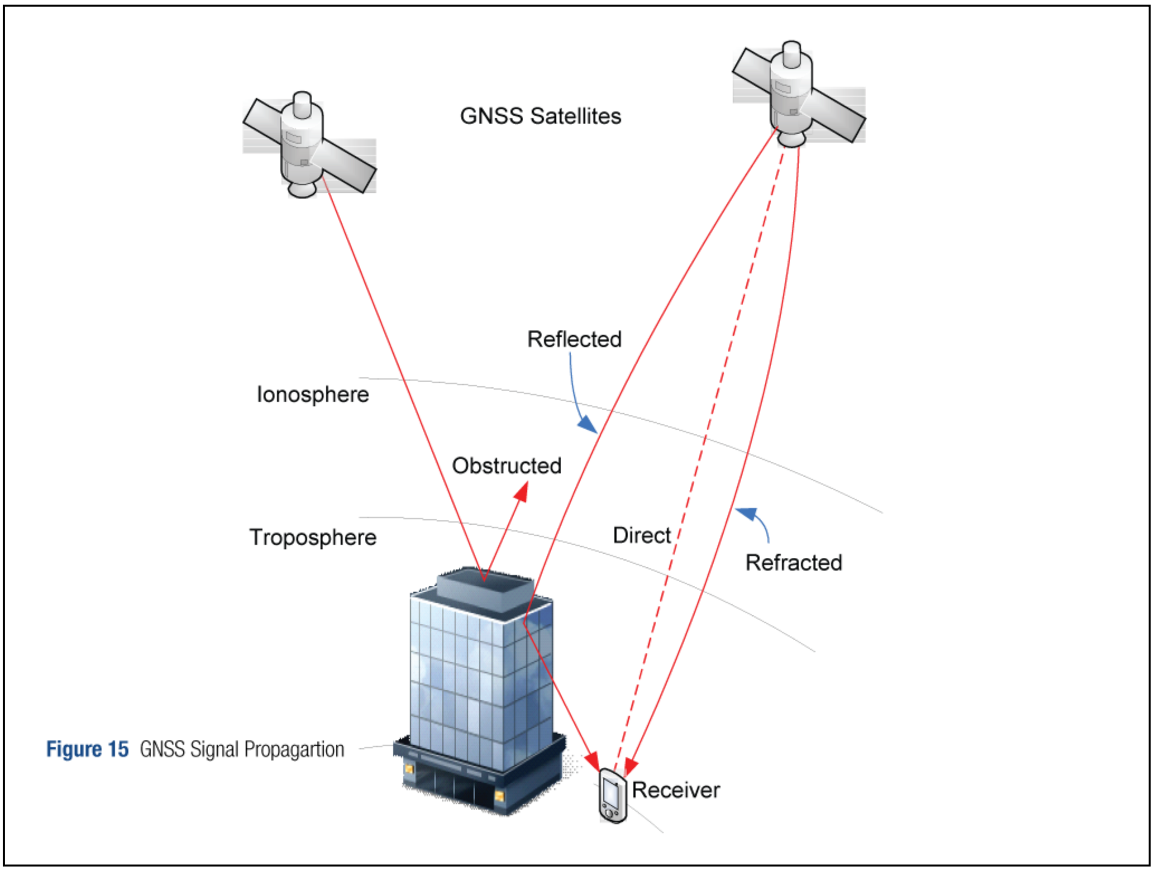
There are numerous potential error sources that can affect the performance of any type of GNSS device. Figure 2.2 displays some of the most common, which are also explained below:

- *Sky availability.* At least four satellites need to be tracked by any GNSS device to derive a position (Uren and Price 2010) and tracking more satellites typically results in greater accuracy. Trees and tall buildings can obscure the sky and prevent the receiver from detecting coherent signals from satellites, reducing the number of satellites available for use in position calculations, and in some cases preventing the receiver from being able to compute its position. Receivers that are able to track and use all available satellites (for example, GPS + GLONASS) perform better in situations with limited sky. Limits on satellite visibility can be countered by enhanced tracking systems such as Trimble's 'Floodlight' system (Trimble.com 2012).

- *Satellite configuration.* If the number of visible satellites is limited and/or the geometry (positions in the sky) of those that are visible does not support a good resolution of position this will affect the accuracy of any derived positions. Position dilution of precision (PDOP) can be used as an indicator of how well the satellite geometry at the time of measurement is suited to the calculation of an accurate position (Uren and Price 2010). Mapping and survey grade receivers report this at observation time, with some consumer grade receivers loosely converting this into a distance accuracy measure. The GPS satellite constellation utilises orbits that are not optimised for New Zealand, so positioning is often more problematic than documented in international literature.

- *Multipath issues*. GNSS receivers calculate position from the radio signals received from satellites so any interference with the path of those signals by reflection will introduce errors into the position calculations. Higher quality mapping or survey grade receivers typically have software enhancements that analyse and reduce the effects of this source of error as well as hardware enhancements (ie choke ring antennae), while lower grade receivers tend to have less capability to resolve errors. Multipath reflection errors are difficult to identify and can cause significant errors in positioning, for example in built-up urban areas.

Figure 2.2 GNSS signal propagation



Source: Jeffrey (2010), p20.

- *Ionosphere and troposphere delays*. The radio signals arriving at a GNSS receiver have travelled from a satellite and through the atmosphere before reaching the receiver. The speed at which the radio signals travel is affected by atmospheric conditions. The positional error in code measurements (see below) introduced by the signals travelling through the ionosphere[1] is typically around 10m but it can be as large as 150m (Uren and Price 2010). Fortunately, it is possible to remove a significant portion of the ionospheric error when two or more signals are measured (for example L1/L2, or in the future L2/L5 or L1/L5). However, at present it is only possible to measure more than one signal with expensive survey grade receivers. The other significant atmospheric effect on the GNSS signals is troposphere[2] delay. Troposphere delay errors are capable of introducing errors of around 2m to 3m at zenith (ie when the satellite is directly above the receiver) into code-based positioning (Uren and Price 2010). The troposphere error is typically reduced with an increase in altitude, but it increases with increasing zenith angle (ie if the radio frequency travels from a horizontal position directly towards the receiver, the error would be more significant).

GNSS observables are subject to the error sources outlined above and some of the positioning methods make use of various hardware, software and measurement techniques to enable varying levels of

[1] The ionosphere is the layer of earth's atmosphere 50km–1000km above sea level.

[2] The troposphere is the layer of earth's atmosphere 0km–15km above sea level.

positioning accuracy. Generally speaking, higher accuracy positioning systems are more expensive to purchase and/or require more complicated procedures to obtain accurate results. The following sections give a brief explanation of common GNSS positioning techniques.

2.1.2 Single point positioning

Single point positioning is the simplest form of GNSS positioning. Most low-cost GNSS compute the distance (or range) to each satellite by tracking the C/A code. The distance from the GNSS receiver to each of the known satellite positions is then used to calculate the position of the GNSS receiver. Basic autonomous (absolute) locations derived from this technology are typically in the order of 5m to 20m accuracy using most consumer grade devices (Uren and Price 2010).

2.1.2.1 Consumer grade devices

This category of single point positioning devices typically used in transport asset management includes recreational GNSS receivers, smartphones and car navigation systems. Typically these receivers are used to derive a position which is sometimes displayed on a base map. The majority of these systems will enable simple storage of points. Consumer grade GNSS is used regularly throughout the transport supply chain for work requiring low accuracy. Examples of some receivers capable of this level of positioning in New Zealand include: Garmin Oregon, Garmin eTrex, Magellan Triton, Apple iPhone, Samsung Galaxy, Nokia Lumia, Tomtom Via series and Garmin Nuvi series.

Wing et al (2005) undertook an accuracy assessment of numerous recreational GNSS devices. Each of the devices was tested in open sky, relatively open canopy forest and closed canopy environments. The results of the positioning averaged out over all tested environments for the various devices at 95% confidence limits ranged from around 4m to 13m. However, the values in the closed canopies (poor sky visibility) were noticeably larger ranging from 10m to 40m (95% confidence).

Zandbergen (2009) undertook an assessment of the positioning accuracy of an iPhone, making use of its consumer grade GNSS, cellular network positioning and WiFi positioning using data that was available at the time. The author does not comment on the use of the devices for road-based applications, nevertheless, the findings on accuracies are relevant in considering the use of such technologies. The paper included an independent assessment of each of the positioning techniques in this bundled option. It found 95th percentile errors for iPhone positioning of 14.4m over a 20-minute period, whereas a consumer grade Garmin, used at the same location had a 95th percentile error of 1.3m. Most assessments of recreational grade receivers such as the Garmin receiver used in this study reported errors around the 15m mark. Based upon the findings of this study it can be inferred that the accuracies of the iPhone are lower than those of a recreation grade GNSS like a handheld Garmin even though they make use of the same positioning technology.

A technology management plan developed for the Louisiana Department of Transportation and Development (DOTD) in 2012 noted several existing of uses of consumer grade GPS devices, including: permit locations, borrow pit locations, railroad inspections, bridge inspections and recording of crash locations (Barnett et al 2012). In this case, the consumer grade GNSS technologies were being used for positioning of discrete locations, rather than assets that were continuous. As part of this research an 18-hour accuracy test on a recreational GNSS was undertaken and the positions over this period were found to vary by up to 30m. It was concluded that the independent use of this data may not be a significant issue, but if the results of the survey were to be overlaid with any other data in a geographic information system (GIS) environment they would not align in any meaningful way. However, the data was useful for locating a known attribute in the field, for example, a bridge or a street sign.

There is a lack of existing research into the practical application of these types of devices in a transport asset management context. However, from a practical viewpoint, these technologies are cheap and easy to use. GPS-enabled cell phones are becoming more and more prevalent, and have many practical applications in a roading context, particularly around navigating to a known point such as an area of flood damage requiring repair, a seal join, a culvert or a bridge. There is a practical limit on the use of this technology. It is unsuitable for recording locations in most asset databases because the positions could be out by 20m and will not match well with the underlying aerial photography or other spatial layers used in a GIS environment.

2.1.2.2 Embedded consumer grade GNSS/basic mapping grade GNSS

As indicated above consumer grade and basic mapping grade GNSS are becoming embedded in many other mobile devices such as smartphones, tablets and watches. There is no improvement in accuracy but the added functionality on the device could make it a more viable option for various asset management and development. A good example of this is the GPS to linear reference conversion tool used at the Auckland Motorway Alliance (AMA) and elsewhere in New Zealand. This application can be used on any modern mobile device with a HTML5 compliant browser.

2.1.3 Differential GNSS (code)

Differential correction of the C/A code is a process whereby a receiver placed at a reference station of known location is used to record the difference between the computed distance (range) and the measured distance (range) to each satellite; this difference (or range correction) is then applied to each measured 'receiver to satellite distance' (range) at the rover site at any point in time. These corrections are applied to a roving receiver in the vicinity of the reference station to enhance accuracy of such locations typically from the 5m to 20m range to the 1m to 5m range for most mapping applications (Uren and Price 2006).

This technique takes advantage of the fact that the errors affecting the GNSS observables at the reference station are similar to the errors affecting the GNSS observables at the roving receiver. This assumption is less viable as the distance between the reference station and the roving receiver increases. Consequently, differential GNSS accuracies are usually expressed as a constant plus a distance dependent error.

The corrections are often applied by a method known as 'post processing' whereby the recorded corrections at the reference station are applied to the GNSS observations in the office after completion of the GNSS survey, although they can be broadcast and used in real time either by local radio or cell phone/internet, or satellite link.

Augmentation is a type of differential correction whereby real-time corrections are derived by tracking satellites at known earth positions and broadcast over a significant geographic extent. This method of broadcasting eliminates the need for the user to operate their own reference receiver. Methods of broadcasting the correction signal are broken into two distinct categories: ground-based augmentation systems (GBAS) and satellite-based augmentation systems (SBAS). GBAS use ground control stations to compute differential corrections and broadcast them directly to roving receivers; high-powered radio or internet are the most common forms of transmitting these signals. As such, their coverage is limited to the coverage of the radio transmitter or to mobile internet reception. SBAS use ground control stations to compute differential corrections, which are transmitted to satellites that then broadcast the signal to a GNSS receiver capable of receiving such corrections.

Examples of SBAS are the US Wide Area Augmentation System (WAAS), the European Geostationary Navigation Overlay Service, (EGNOS), the Japanese Multi-functional Satellite Augmentation System (MSAS), and the Chinese Satellite Navigation Augmentation System (SNAS). New Zealand is in the 'footprint' of the WAAS and MSAS systems, but extensive coverage is not available. Trimble's OmniStar system is available and a number of mapping grade receivers are enabled for this technology, with annual subscriptions in the order of $2500–$3000 per annum per receiver. Accuracy of differential GNSS is conservatively estimated in the 1m–3m range depending on the receiver and distance of baselines (Arnold and Zandbergen 2011).

The Cooperative Research Centre for Spatial Information (CRCSI) in Australia prepared a briefing document (www.crcsi.com.au/getattachment/2a89c330-42b3-4907-98ee-d535e03a425d/.aspx) investigating the viability of a SBAS for Australia that would enable 1m–2m positioning accuracy across the country. The report outlined the numerous benefits of such a system, and recommended that an opportunity was found to install SBAS equipment on another satellite. CRCSI is a government, industry and research joint venture which uses spatial technologies to make a significant contribution to the economies of Australia and New Zealand. It conducts research and development projects that involve collaboration between government, corporate and academic resources, and is funded by Australia's Cooperative Research Centre Program and by participant contributions. New Zealand CRCSI partners include LINZ; University of Canterbury; and a consortium of companies including Critchlow; e-Spatial; GeoSmart; SKM; Trimble; we-do-IT; and ZNO.

Devices making use of this type of differential GNSS technology are typically referred to as mapping grade receivers. For the purpose of this research they have been divided into two categories – mapping grade and enhanced mapping grade – to allow for separate evaluation of finished location technology products with certain characteristics. For the most part, they all have the same/similar accuracy specifications; the point of difference between the two groups is essentially coverage.

2.1.3.1 Mapping grade

Mapping grade receivers use code-based positioning, and are capable of making use of one or more of the differential correction methods outlined above. The resulting accuracies of the system at the 95% confidence interval are in the order of 1m–5m and possibly better in some situations.

This type of location technology is now widely used by the Transport Agency's contractors and other service providers operating within the highway corridor, such as electricity lines companies. The Transport Agency's high-speed data capture service providers use this technology, and some contractors use it for mapping as-built positions. The devices are capable of capturing point, line and polygon information spatially, and recording attributes against them.

The Louisiana Department of Transportation and Development (DOTD) has documented its use of mapping grade receivers for various applications (Barnett et al 2012):

- *Road inventory*. Three trucks with mapping grade GPS units were used to drive roads and collect spatial information around road widths and levels as well as point data like schools and fire stations. Following capture the data was downloaded to allow post-processing of the data (presumably differential corrections). Results in expected accuracies, or accuracy obtained were not presented.

- *Mapping of environmental and archaeological sites*. Trimble GeoXT mapping grade GNSS devices were used to collect spatial information for use in ArcGIS software and users were able to display existing GIS information on the device for viewing in the field. The expected accuracies resulting from the use of this device were in the order of 1m. The resulting observations were downloaded electronically and differential corrections applied before they were incorporated into a GIS database.

- *Levee inspection*. Trimble Yuma devices were chosen to map levees, fences, ramps, slides and washouts associated with levees.

Mitchell et al (2008) reported the use of a mapping grade GNSS receiver for positioning sideway-force coefficient routine investigation machine (SCRIM) measurements. An existing road centreline reference position was created using a combination of existing static GNSS surveys and aerial photography. The reference centreline provided a base to enable comparison of SCRIM results to an existing position on the road. While the SCRIM data was being recorded, a differential mapping grade GNSS was used to position the equipment at a frequency of 100Hz. The resulting positioning of the SCRIM data achieved an accuracy of approximately ±1m each year, a significant improvement upon the conventional linear referencing systems previously used.

Pérez-Ruiz et al (2011) undertook an assessment of GNSS differential correction signals, including the OmniStar Virtual Base Station service provided by Trimble, which is available in New Zealand. After recording in excess of 30,000 results, the system produced a root mean square (RMS) error of 0.5m (95% confidence). This system would be suitable for positioning in real time with mapping grade GNSS receivers. This system provides one example of being able to obtain real-time correction data to enable sub-metre positioning with mapping grade receivers in New Zealand. Additionally, after the hardware is configured there is likely to be little difficulty for users to obtain the necessary positioning accuracy.

Serr et al (2006) tested four mapping grade GNSS receivers in America on 15 known position base stations over a one-month period. The receivers were: Trimble Pro XR, Trimble GeoXT, Trimble GeoExplorer II and a Pharos mapping grade receiver. The ProXR and the GeoXT were both positioning at the 1m level after the differential corrections were applied, the GeoExplorer II was at the 3m level, and the Pharos was at the 6m level. It is important to note that these accuracies were obtained in optimum GNSS positioning environments so it is unlikely that this level of accuracy would be obtained 95% of the time in the various environments that are be encountered in roading.

The combination of the uses and operability outlined by Barnett et al (2012) and Mitchell et al (2008), and the accuracies reported by Pérez-Ruiz et al (2011) and Serr et al (2006) suggest that this level of positioning system is suitable for some transport asset management data capture, and it would be suitable for navigation to an exact location in the field.

One potential issue with this level of technology is that it assumes user understanding, and in many cases also requires post processing. Users are likely to need training in the use of differential corrections (real time and post processed) and it is important that users understand the accuracies they are obtaining with and without differential correction. Based on Opus experience with similar software it is likely that users will take a few days in the field with an experienced operator to get to the point where they can use the menus within the controller alone in an efficient manner.

2.1.3.2 Enhanced mapping grade

Enhanced mapping grade devices are similar to the standard mapping grade device but specifically include software and hardware improvements designed to improve satellite tracking by GNSS receivers. One example is the Trimble 'Floodlight' (Trimble.com 2012) which claims to significantly improve a GNSS receiver's tracking precision. This technology is available on some of Trimble's more expensive handheld receivers. Unfortunately, at present, there is inadequate independent research quantifying the accuracy improvements obtained with such technology.

2.1.4 Differential GNSS (carrier phase)

Differential carrier phase measurement currently provides the best GNSS-based positioning but the equipment at $10,000–$40,000 per device is significantly more expensive than single point positioning equipment. It is relatively specialised because of the high cost of the equipment and the processing techniques used. However, there are some lower cost options that make use of open source positioning algorithms, and web-based corrections to achieve far greater accuracies than those typically obtainable with low cost/single frequency devices. However, these technologies are in their infancy and are not refined to the point where those without specific knowledge can use them.

Real-time kinematic (RTK) satellite navigation is a technique used to enhance the precision of position data derived from satellite-based positioning systems. RTK positioning accuracy is dependent on the type of receiver, the distance between the reference station and the rover, and environmental factors such as multipath effects. It is possible to obtain positions accurate to the decimetre or even centimetre level when care is taken.

There are two types of RTK solutions available: conventional RTK (those with a single base receiver), and network RTK (those with a network of reference receivers). Single-base systems make use of radio or cell phone broadcasted corrections between the base receiver and a moving rover within 30km. Those systems with a network of reference receivers have far greater coverage because they are capable of modelling the errors affecting the GPS observables. Both systems typically use radio or internet to transmit the corrections to the rover. Consequently, the coverage of both systems is limited to areas with cell phone or radio coverage. The significant advantage of the network-based solution is that the distance dependent errors are significantly reduced and almost eliminated, network-based corrections have been disseminated via satellite link around the world but this is not currently common practice within the New Zealand transportation industry.

2.1.4.1 Survey grade GNSS

Survey grade GNSS receivers are capable of achieving accuracies well above requirements for most transport uses. They have also been used in some cases by consultants for positioning of linear referencing management system (LRMS) road markers. However, they are not a realistic solution for the wider transportation industry due to the significant capital cost. Survey grade GNSS receivers are capable of real-time absolute positioning at sub-decimetre level (Uren and Price 2010). However, use of this technology and its limitations requires advanced user knowledge. In instances when this level of accuracy is required, it would typically be more cost effective to approach people with existing knowledge and equipment to undertake that work.

2.1.4.2 Low-cost systems

Some researchers have been working on improvements to processing algorithms that make it possible to accurately position at decimetre level using low-cost equipment. Both of the systems make use of a web service which uses industry standard file formats to produce differential corrections for GNSS observations to these low-cost receivers. It is not yet clear whether these systems work in New Zealand due to our predominantly sparse infrastructure, nor have they been tested here specifically. However, they are mentioned because it is likely low-cost accurate positioning systems, although not currently developed for easy use, may be available for future decimetre level positioning. At that time, the integration of such a system into mobile asset management field devices would result in a powerful system meeting most requirements of potential users.

Takasu and Yasuda (2009) made use of RTKLIB, an open source GPS processing software to construct a GPS receiver that was capable of accurate (decimetre level) real-time positioning and cost only $400. The positioning was not as robust as that of a typical survey grade receiver but it was sub-metre. Similarly, Realini et al (2012) discuss the use of open source goGPS software which can be used for either real-time, or post-processed decimetre level positioning using low-cost GPS receivers.

2.1.5 GNSS simulation

Although not GNSS in the true sense, another growing area of technology is networks of pseudolites, also referred to as ground-based constellations. Attempts have been made to develop this technology since the 1970s but have shown little real world promise due to a range of problems, such as siting of locations, transmission strength and time synchronisation. Rizos et al (2011) describe a new form of ground-based constellation called Locata which shows great promise as a localised terrestrial replica of GNSS. This technology consists of a network of Locata devices, for which centimetre-level accuracies have been achieved.

A recent Austroads report (Austroads 2013) on cooperative intelligent transport systems (C-ITS), has also reviewed Locata and states that the technology has great potential to enhance accuracy and overcome GNSS blockage in areas such as tunnels, under bridges, urban canyons and dense forest. In terms of cost the receivers would be similar if not the same as GNSS receivers but there would to be a significant investment in developing a network of Locata devices.

2.2 Other wireless systems

A wireless network refers to a system for the transmission and reception of electromagnetic waves (radio networks). These networks may have other primary uses such as telecommunications but they can also be used for location purposes. Potentially all wireless or radio signals can be used for positioning purposes and there are also a number of different approaches, such as using the power levels received, the time of flight, or the direction of arrival (Samama 2008).

Apart from satellite and ground-based radio networks used in GNSS, other wireless technologies that may have application in the transport sector include mobile telecommunication networks, Wifi and Bluetooth. On top of this there are a multitude of other radio systems that can be used for location purposes, as explained by Samana (2008). These include amateur radio, long-range navigation systems, and other satellite radio systems like the Argos system which uses a Doppler-based positioning technique.

In this section, wireless technologies are split into tracking systems, local area systems like Bluetooth and Wifi, and wide area systems like telecommunications networks.

2.2.1 Passive tracking systems

Tracking systems refer to technology that has been developed primarily for the tracking of assets, objects or people. The entity that is being tracked has a tag which holds information related to itself. Active sensors can then be used to pick up information from tagged objects within a certain proximity.

Primarily, this technology has shown great application within the transport logistics and intelligent transport systems (ITS) sector. In the case of transport asset management the most obvious solution is to tag road markers or assets that fall within the road corridor and as a vehicle or person travels within a certain distance of the object, information from that object such as its location and attributes will be transferred to a mobile device. Radio frequency identification (RFID) is a good example of this and could be used to provide information to people working along the state highway. A paper from de la Garza et al (2009) outlines some potential uses of RFID tags in highway asset management, with one option being to place tags on the asset, or use them to assist locations in the field alongside current highway posts and markets. Similar to RFID, quick read (QR) codes could be used to tag assets or locations in the field (Nikander et al 2013).

Although the technology itself is inexpensive and relatively easy to use, it would require significant investment to set up a network of tagged objects and maintain these over time. This technology could be a valid way to provide location information in areas with little GNSS coverage such as forested areas, tunnels and urban canyons.

2.2.2 Local area systems

Bluetooth and Wifi technology has been developed primarily to exchange data wirelessly between devices (Bluetooth) or over an established network (Wifi). In terms of using these technologies for location purposes, most effort has focused on indoor positioning; one reason for this is that both technologies are already well integrated within many office layouts and also because GPS/GNSS has limited use inside a building.

Within the transport sector, Bluetooth has predominantly been used for vehicle tracking surveys to undertake travel time estimations and origin–destination matrices (Rieser-Schüssler 2011; Koprowski 2012). In New Zealand, the Transport Agency has already utilised Bluetooth to track vehicle speeds and congestion on a number of projects, with one such trial outlined by Beca on the Puhoi to Warkworth Pilot Study (Beca Infrastructure Ltd 2011). The main requirement for Bluetooth tracking is an antenna and a master device that scans the area and detects discoverable Bluetooth devices. For each device its unique media access control (MAC) address, the timestamp, the received signal strength and the position of the master device is stored. When several master devices are installed in an area or along a corridor, the movements of individuals can be tracked through their MAC addresses (Rieser-Schüssler 2011).

Wifi has been more successfully used in outdoor environments to assist in positioning solutions in areas with poor GPS coverage. Wifi positioning relies on WiFi access points which over recent years have been widely deployed by both homeowners and organisations. These access points typically broadcast a signal which can travel several hundred metres in all directions. WiFi positioning software identifies the existing signals within range of a WiFi enabled mobile device and calculates the current location (Zandbergen 2009).

A successful positioning technology used by both Bluetooth and Wifi is ‘fingerprinting’ whereby access point (APs) signal strengths are observed at known locations to develop a ‘fingerprint’ unique to that location. This can then be used later in the field to match observed Wifi signals with this database (Zandbergen 2009; Bekkelien 2012).

Both Google and Apple have made significant investments in non-GNSS location systems. Apple has recently purchased a company called WiFiSLAM that integrates Wifi with an inertial navigation system (INS) and GPS and shows some promise. There are other similar technologies which will operate over larger areas, such as WiMAX.

Ultra wideband wireless networks are another promising technology with good application as a real-time locating system, using precision time-of-arrival measurements (Gartner 2013). The accuracy of ultra wideband wireless is an advantage as it can achieve centimetre level. However, an issue is range of coverage, with high positioning accuracy requiring a distance between receivers of less than 10m (Austroads 2013).

Some of the technologies mentioned above have primarily been developed for use within a building, but could provide real solutions for parts of the Transport Agency network that have limited GNSS coverage.

2.2.3 Wide area systems

Wide area systems refer to networks that generally operate across metropolitan, regional or national boundaries. The most widely used of these systems are mobile telecommunications networks and there are a few methods to detect location using these networks, the easiest and least accurate is by simply assigning the phone to the base station, which is transmitting with the strongest field strength, this method is known as cell identification (cell ID) (Zandbergen 2009). The accuracy depends on the cell size and density of the network. When a mobile phone is within range of multiple base stations, location can be calculated by measuring the time of arrival of the signal from known base stations. However, owing to poor time accuracy in mobile networks, location accuracy is still low (>50m), and thus not appropriate for transportation asset management, but some applications may be appropriate for higher level strategic studies.

Another wide area system is commonly known as GNSS simulation or a ground-based constellation of pseudolites. This technology was discussed briefly in section 2.1.5.

2.3 Remote sensing and analysis

In this section the remote sensing technologies and the analytical techniques which can be used to help locate features are reviewed. Passive sensing technologies include aerial and satellite imagery. Active sensors are often referred to as detection and ranging methods, and cover technologies such as LiDAR, radar and sonar. An active sensor carries its own emitter of radiation that illuminates the sensed objects and causes reflections that are gathered by the receiver of the active sensor (Zipf and Jöst 2012).

For both active and passive sensors, as long as the location of the sensor is well defined then they can create high accuracy datasets which can be used to locate other features. This sort of technology generally requires the use of platforms like GIS but potentially also computer-aided design (CAD) and remote sensing software. It also requires access to reliable contextual datasets like aerial and satellite imagery and other GIS datasets that can be used to locate features.

These datasets can be expensive to generate the first time around, but have many potential uses, which is why they are commonly procured for urban areas and important infrastructure networks around the world.

2.3.1 Examples

There are many different combinations of the above techniques and platforms. As some of these are relatively common uses of GIS, there is little specific literature. This review is largely informed by engagement with key GIS industry organisations within New Zealand.

First, and most simply, these techniques can be used to locate features in a desktop environment without leaving the office. An example might be identifying road centrelines from aerial imagery. One simple option for this would be the use of a customised Google maps tool with high resolution imagery (K Subramari, pers comm, 22 March 2013) or the use of desktop GIS packages like Esri ArcGIS with access to good background datasets, such as local authority LiDAR. These methods can either be used to locate a feature without ever entering the field, or also to update features in a desktop environment after having been in the field (Barnett et al 2012).

An example of the latter approach is a project that was undertaken by the AMA in 2011 to define vegetation maintenance boundaries along the motorway network (C Bannock, pers comm, 2013). Initially, an ecologist undertook a low accuracy survey in the field with a Trimble Juno to define areas of similar vegetation and then the actual boundaries of these vegetation zones were digitised from high resolution recent aerial imagery using Esri ArcGIS.

These methods can also be set up on a mobile platform, which is often termed mobile GIS. This type of system will allow either of the above options, but is operable in the field, and adds the benefit of having access to real-world information. An example of this could be pocket RAMM, which is provided by RAMM Software Limited (RSL) and is already widely used by contractors although mainly for job control rather than asset location. Other examples could be a GIS package installed on a Trimble Juno (Trimble Navigation 2013) or a Topcon Tesla (L Schutte, pers comm, 17 Jan 2013). There are also numerous tablets that could be used to perform similar functions; from ruggedised tablets such as motion tablets (T Elson, pers comm, 19 Feb 2013) and Ubiqon T70C (S Lowe, pers comm, 11 Feb 2013) through to consumer Android and Apple tablets, which can be set up with a myriad of applications to undertake imagery-based field data capture.

One example of this could be the digitising of stormwater manhole locations in the field, from high resolution imagery using low accuracy GPS. In the field the surveyor is able to find his or her general location, then confirm the asset type as a manhole, and use the imagery to specify an accurate location. There are not many examples of this in the literature but it is a technique that has been used by Opus, most recently in 2010, in a condition survey of stormwater assets in Christchurch.

Last, it is also worth mentioning the use of advanced analysis methods to define feature locations using a number of input datasets. This would normally be undertaken in a desktop environment using GIS or remote sensing software. An example of this is definition of the surface area of different land cover types using image reflectivity and colour mixed with LiDAR intensity. Recent research in the USA (Vaghefi et al 2012) has looked at a range of remote sensing techniques to evaluate highway bridge conditions, and this found some applications for aerial imagery. Current research in this area is also being undertaken by the University of Colorado in the USA, to classify road surface quality and land cover using high resolution imagery (Emery 2012). Also in the USA, the National Consortium on Remote Sensing in Transportation has undertaken a range of relevant research.

Within New Zealand, the land cover database (LCDB) owned by the Ministry for the Environment, is an example of a large remote sensing initiative to locate different land cover environments (Ministry for the Environment 2009). Auckland Regional Council undertook work to map impervious areas using aerial imagery (Samama 2008). It is also worth noting there is a general trend towards making data more publically available (eg creative commons licences) and accessible (eg web services) within New Zealand. A good example of this is the LINZ Data Service. This trend will facilitate this sort of analysis in the future. One of the strategic objectives of CRCSI is the automated generation of the spatial information products program. This program is focused on automated remote sensing and one current project is looking into feature extraction from multi-source airborne and space-borne imaging and ranging data (CRCSI 2013a). One relevant research area is the automatic 3D reconstruction of objects (both man-made and natural) such as building models from imagery and LiDAR, which could have future relevance for large assets on New Zealand state highways.

There are other sensing technologies which show some promise for roading asset management. Examples of these are camera matching and object detection from ground-based LiDAR. In the case of camera matching, there has been research into estimating speed based on successive frames of a video and using these to correct inertial measurement unit drift (Chu et al 2012). Other similar examples of this sort of technology include the generation of 3D point clouds from stereographic images enabling distance and depth measurements (Geomatic Technologies 2013).

2.4 Inertial navigation systems

INS detect the change in an object's position, velocity (speed and direction of movement) and orientation (rotation around an axis). The technology used for tracking these changes is referred to as inertial measurement units (IMU). These units use a combination of various equipment in the following ways (Perrone et al 2008; Artes and Nastro 2005):

- accelerometers to measure the linear acceleration of an object
- gyroscopes to measure the angular velocity of an object to track change in direction
- magnetometers to correct gyroscope and accelerometer readings.

INS is benefiting greatly from advances in micro-electro-mechanical systems (MEMS) technology. This enables the creation of low-cost measurement units as listed above (Toledo-Moreo and Zamora-Izquierdo 2010).

INS is similar to other referential location technologies (such as trip meters), in that it requires a previous known position, usually gained through GNSS, as a base for measurements. The further the object moves from the last known location, the more errors will accumulate in the measurements until another known location is added.

2.4.1 Examples

INS is widely used in the transport supply chain and is commonly found within many commercial vehicles to track position. When integrated with GNSS and other location technologies it is an important component of a mobile mapping system (MMS) (Bassani et al 2012). Within the land transport sector they are generally used to provide low accuracy (>3m) positions for vehicle navigation and to also provide a backup system for vehicle navigation when GNSS coverage is poor. High accuracy (and high-cost) examples of MMS can be found that make use of a combination of GNSS and INS, ie LiDAR and terrestrial mapping systems.

In terms of most consumer vehicle navigation systems it is more important to provide continuous and reliable navigation, rather than high-accuracy locations, although with the future trend towards autonomous cars the requirement for higher accuracy IMU systems may increase to the sub-metre level (Godha 2006).Trials have also attempted to integrate IMU devices with feature matching camera technology to provide accurate location where GNSS coverage is sparse (Chu et al 2012). In situations where good GNSS coverage is low, it is reasonable to assume that INS could replace traditional trip-meters in some cases.

There has also been some research into using IMU for pedestrian surveys which could be relevant for asset management within areas of sparse GNSS coverage. One area of recent research is personal dead-reckoning devices, which are basically small IMUs fitted to the boots of a pedestrian which are then used to track movements from a known location. This sort of technology could be used to find or update an asset's location if you are within a short distance of a known location (<50m). This sort of technology leads to an accumulation of errors the further you move from a known location. Beauregard and Haas (2006) found that errors are in the range of 2% of the distance travelled so to keep within a 3m accuracy you would need to travel less than 150m from a known location. Kwanmuang et al (2011) used a magnetometer enhanced pedestrian mounted IMU and managed errors less than 1.5% of the distance travelled. There has also been some recent work by Romanovas et al (2013) to augment pedestrian mounted inertial sensors with known RFID tag locations to increase accuracy.

2.5 Trip meters

Similar to IMU, odometers and trip meters track the distance a vehicle travels in relation to a start point. An odometer usually refers to the total distance travelled by that vehicle, and a trip meter can be reset for each separate trip. In modern systems these operate by counting the rotation of the wheels of the vehicle using a sensor and then converting this into a linear distance (Samama 2008). As with other relative measurement systems, it is important to take into account that the error will propagate the further a vehicle moves from a known location.

To be used as a location technology, it is also essential that the trip meter measurements are managed within some form of linear referencing system to enable locations to be derived from a measured distance. This represents a good model of the transport network, which is represented by a series of nodes and links both digitally and in the field by physical markers and points. This sort of system then enables field measurements to be converted into a location.

2.5.1 Examples

Trip meters are widely used to both find features and record or update locations of features/events on a road network. They are particularly useful as they work regardless of GNSS coverage being available and they also take into account the three dimensional length of a road. In the past, due to poor satellite coverage and lack of good GPS devices/software trip meters have often been used in road asset management as they are generally robust and user-friendly (Perrone et al 2008). However, with GPS now widely accessible to people working within the transport industry, some uses of trip meters have become obsolete.

Mitchell et al (2008) state that with modern odometers accuracies on straight sections of road of better than 1m per kilometre are achievable, but the drive line of the vehicle can have a notable impact on this, so for curves and steeper gradients, the accuracy can reduce to 4m to 5m per kilometre, which can then give accumulated errors of around 50m on long sections. In particular, this research discusses the reasoning behind the move from a trip meter-based survey to a GPS survey. A report by AustRoads (Kelly and Chen 2011 gives a good description of the different types of linear referencing systems and trip meters used across Australasia.

Along with magnetometers, odometers and trip meters are also useful auxiliary sensors to prevent error degradation for INS (Godha 2006).

2.6 Offset technology

Offset technology is a simple, practical system used in conjunction with another location technology. It is derived from a basic surveying method called a 'baseline survey', where offsets to objects are measured from an accurate baseline. Three measurements are recorded:

1. The cumulative distance along the baseline
2. The measured offset at right angles to the baseline
3. The direction of the offset, either right or left in relation to the increasing baseline distance.

Prior to the widespread use of electronic survey instruments in the 1980s, this method was traditionally used by New Zealand surveyors to define natural boundaries, such as the edge of streams or lakes.

2.6.1 Examples

Offset technology is widely used in transport asset management where the road centreline serves as the baseline. Distances along the baseline are measured from a known point (the route station) using a trip meter. Offsets from the road centreline to the object are measured by rototape or tape measure, and recorded together with the offset direction. More modern offset technology includes laser range finders such as those found on ikeGPS technology.

While this system is relatively simple, it is still subject to the cumulative errors in baseline measurement as outlined in section 2.5. It can also become complicated by road layouts, such as roundabouts and divided carriageways.

2.7 Mobile mapping systems (MMS)

A MMS is a vehicle-based combination of location technologies to undertake high-accuracy, multimedia surveys of a transport network. There is nothing specifically new about each individual technology but of more interest is the integration of high accuracy GPS, INS, trip meters and video to produce a dataset which has applications to undertake more in-depth analysis of the road network from a desktop environment.

Examples of MMS include the high-speed survey vehicle used by WDM Ltd (Mitchell et al 2008), the Terralink StreetCam3D system (Grant Kilkolly, pers comm, 29 Jan 2013), the Topcon IPS-2-HD (Louie Schutte, pers comm, 17 Jan 2013) and the Geomatic Technologies AIMS system (Geomatic Technologies 2013).

2.8 Geographic information systems (GIS) software

A GIS is generally defined as a system for storing, managing, analysing and displaying geographic information. A GIS by itself is not a measurement technology but it is an excellent tool to define the location of features based on surrounding geographic datasets. It is also extremely useful for both quality control of current location information and also the update and editing of existing location information based on other datasets. GIS software ranges from being completely free through to costing thousands of dollars for a single licence seat. It is now used widely and integrated within most government departments, local authorities and many private organisations in New Zealand. This makes GIS an excellent tool for sharing location information.

2.8.1 Examples

GIS software can be split into three main categories:

1. Desktop GIS software packages such as Esri ArcView, Pitney Bowes MapInfo and Intergraph Geomedia or the Open Source Quantum GIS
2. Mobile GIS software packages like Esri ArcPAD, MapInfo MapX and countless IPAD and Android applications
3. Web-based and service-orientated approaches such as ArcGIS for Server, MapInfo Stratus and other open source applications like MapServer and GeoServer.

More recently, cloud-based services have been developed that enable an organisation to run their whole GIS from a cloud environment. Some examples of these include Esri ArcGIS online and GISCloud.

Generally all of these GIS packages contain tools to both define and update asset locations. To make GIS even more useful within the transport sector, on top these basic tools, GIS functionality has also been added onto many existing transport asset management software packages (such as RAMM GIS), or specific transport extensions have been developed for major GIS suites of software (such as Esri Roads and Highways).

Asset management systems with GIS functionality enable a user to access detailed asset information against a transport asset, which can assist greatly with the quality assurance of asset locations. Transport extensions added to an existing GIS software package can add a number of advantages, such as better management of data against linear networks, or specific analysis tools related to linear networks.

Within the transport sector there are some other considerations when looking for a good GIS:

- an ability to manage linear referencing systems
- good network analysis and modelling functions
- integration with transport asset management systems and CAD software
- an ability to view data in 3D and utilise ground based LiDAR.

2.9 Geospatial hypermedia software

Kong and Liu (2011) define geospatial hypermedia as the integration of web and multimedia technologies with geographic information science. This is quite a broad technology area, which basically revolves around extending the use of traditional GIS with other media such as images, video and audio.

Similar to the GIS examples given above, geospatial hypermedia can also allow the location of features in the field to be identified without leaving the office. On top of other datasets like imagery, a hypermedia system can allow the identification of features of geo-referenced street level videos and images. Within the transport sector these types of packages are generally referred to as road asset management systems.

2.9.1 Examples

One of the most common and widely used examples of this technology group is Google's Streetview which allows users to view street-level imagery by interacting with the traditional Google Maps or Earth interface. This technology can be widely used within the transport sector and is generally free to use and access. It potentially allows the identification and location of features in the field without having to leave the office.

Google Streetview has the benefit of being easy to use and cheap to access but one negative aspect is that the images are not taken at regular enough intervals for some uses, and also the functionality of the Google interface is relatively basic (which is obviously beneficial for ease of use).

Where multimedia information is available for a road network such as that surveyed by a MMS then there are many other custom applications that have been developed to allow a user to easily interact with this wealth of information. Within New Zealand there are a number of similar such applications used within the land transport sector, as outlined in table 2.2 below.

Enhanced 3D GIS systems that can utilise point cloud data along with imagery and other asset information to undertake asset data capture and condition assessments in a desktop environment, is an area of great promise. The collection of ground-based LiDAR is becoming more common and will eventually be cost effective across large parts of the roading network. What is lacking at the moment is software which can process and turn this into useable information.

Table 2.2 Road asset management systems available in New Zealand

Product name	Developed by	Description
JunoViewer	Juno Services Ltd	A portable tool for analysing network condition data
Contour Storyteller	Contour	Video and map viewing distributed with contour camera
RoadRunner	Argonaut Ltd.	The Transport Agency developed web-based intergraded high-speed data (HSD) video and RAMM data viewer
Compendium	Opus	Integrated HSD video and RAMM data viewer with GIS component

3 Technology evaluation

A set of 12 key performance indicators (KPIs) with high, moderate and low ratings was developed to ensure a consistent approach to evaluating location technologies. From the literature and technology review detailed in chapter 2, a summarised list of location technologies was defined and categorised for evaluation against each KPI.

3.1 Key performance indicators

The KPIs are summarised in table 3.1 and the rationale behind the high-moderate-low rating for each KPI is given below. All indicators were also assigned a weighting from 10 to 1 based on the relative importance of that indicator to the overall scoring of a specific technology. The indicators below are listed in order of the weighting value from highest to lowest.

Table 3.1 Summary of key performance indicators

Performance indicator	Rating		
	High (score = 3)	**Moderate (score = 2)**	**Low (score =1)**
1 Accuracy (weighting = 10)	<1m For 95% of measurements	1m–3m For 90% of measurements	>3m For 68% of measurements
2 Affordability (weighting = 10)	<$500 per rover <$500 per office	$500–$2000 per rover $500–$2000 per office	>$2000 per rover >$2000 per office
3 Set-up costs (weighting = 4)	Negligible start-up costs	Start-up costs exist but do not require business case	High start-up costs require detailed business case to get funding
4 Ease of use by contractors (weighting = 4)	Little training required (<2 hours), familiar technology	Moderate training required (2–8 hours), limited support required	Intensive training required (8+hours), extensive support required
5 Applicability to common uses (weighting = 4)	Easily applied to all common uses	Some customisation required to encompass all common uses	Significant gaps requiring alternative technology or extensive customisation
6 Geographic coverage (weighting = 2)	>95% coverage >95% of the time	90%–95% coverage 90%–95% of the time	<90% coverage < 0% of the time
7 Future outlook (weighting = 2)	Clear path for future upgrades to improve accuracy and utility, little modification required, full backward compatibility	Expected increase in accuracy with no clear development path for new technology, moderate adaption anticipated	Any increase in utility will require extensive adaption
8 Track record (weighting = 2)	Commonly used in New Zealand and overseas in network asset management	Some existing use in network management overseas	Some examples of use which show promise of adaptability to network asset management
9 Suitability for network contract trial (weighting = 2)	Pilot studies can be readily set up live in existing Transport Agency network contracts using existing	Pilot study can be run in parallel with existing Transport Agency network contracts,	Pilot study must be modelled by research workers independent of live operations

Performance indicator	Rating		
	High (score = 3)	**Moderate (score = 2)**	**Low (score =1)**
	workers with little disruption to operations	involving existing workers	
10 Integration with RAMM software (weighting = 2)	Compatible with easy upload/download using existing applications	Some simple application customisation required	Significant application development required
11 Location derivation (weighting = 1)	Directly reads and records absolute coordinates and can handle NZ Transverse Mercator (NZTM) and other NZ Geodetic Datum (NZGD) 2000 projections	Directly reads and records absolute coordinates but requires customisation to NZGD2000/NZTM	Indirectly derives absolute locations from other relative measurements
12 Suitability as back-up technology (weighting = 1)	Readily available to most staff in normal course of events, known technology to staff	May require some additional low-cost equipment in vehicle, known technology to staff	Will require specialist equipment and/or applications and training

1 Accuracy

Accuracy is defined as how close the recorded measurement of an object or event is to the true location of that same object or event. A high rating of '<1m for 95% of measurements' was drawn from the project briefing and reaffirmed at the initial steering group workshop. A moderate rating of '1m–3m for 90% of measurements' was assigned as being in line with the best accuracy that is achievable by the mid-range devices known prior to undertaking the research. A low rating of '>3m–10m for 68% of measurements' is similarly in line with expectations of accuracy of well-known, low-cost current technology.

The focus of this research was accurate and affordable location technology, so accuracy was given the highest **weighting of 10**.

2 Affordability

High, moderate and low ratings of <$500, $500–$2000 and >$2000 respectively were derived for either mobile rover units used in the field or stationary units based in an office or headquarters. The high rating is based on the figure the Transport Agency's key providers have already been willing to invest in field technology and recognises some additional investment in software to make the best of use of devices. The moderate rating was derived from discussions at the initial steering group workshop, where contractors would consider an investment of this scale as reasonable if devices enabled field staff to efficiently achieve all location-based tasks. The low rating applies to all more expensive technologies.

Similar to accuracy above, affordability is a fundamental requirement of the technology so this was also given the highest **weighting of 10**.

3 Set-up costs

Some location technologies require a fair investment to get started and possibly then have relatively low on-going costs. Some of these costs may be large upfront investments in platform software, servers or hardware, while other costs may relate to investing in new staff with skills to manage the process. The measurement of this KPI is based on the requirement to access significant additional funds to set up the use of this technology within an organisation. This is independent of the costs to buy individual units or devices for use in the field. A high rating of 'negligible start-up costs' refers to little or no additional costs to the business to prepare for an implementation. A moderate rating of 'start-up costs exist but doesn't require business case' refers to some set-up costs that can be covered within the normal operations of a company. Lastly a low rating of 'high start-up costs require detailed business case to get funding' refers to set-up costs that would require a request for additional funding through a business case for large companies, or additional external funding for a smaller company.

Set-up costs also relate to the overall affordability of the technology so were given a medium **weighting of 4.**

4 Ease of use by contractors

At the initial steering group workshop it was deemed critical that the implementation of any location technology be practical for use by the Transport Agency's contractors. This KPI is designed to capture the ease with which technology can be used by all levels of contractor staff, independent of the cost of the technology. A high rating of 'little training required (<2 hours), familiar technology', identifies technology familiar to field and office operators, and requires minimal training to enable day-to-day use without the need for extensive support. A moderate rating of 'moderate training required (two to eight hours), limited support required' means the technology can be implemented with a moderate amount of training and some initial support as operators become familiar with new or different ways of doing day-to-day tasks. A low rating of 'intensive training required (8+ hours), extensive support required' means the technology will meet the contractors daily needs but because of inherent complexity or a completely new interface will require intensive training and on-going support over an extended period.

As enhancing the use of location technology by contractors is a focus of this research, it is important to highlight the ease of use, so a medium **weighting of 4** was given for this indicator.

5 Applicability to common uses

A set of the five most common roading contractor uses for location technology, shown in table 3.2, was developed following workshop input. The KPI ratings reflect how well a location technology fulfils the needs in each case. A high rating of 'easily applied to all common uses' refers to a technology that readily meets these requirements. A moderate rating 'some customisation required to encompass all uses' captures technologies that with some customisation or adaption will meet these requirements. A low rating 'significant gaps requiring alternative technology or extensive customisation' distinguishes technologies that are not suitable for all common uses, or will require significant customisation and or new infrastructure to meet the requirements.

Meeting a contractor's specific needs for location technology is equally important to ease of use. A medium **weighting of 4** was allocated.

Table 3.2 Common roading contractor uses for location technology in the New Zealand

Item	Description	Examples	Comment
1	Finding or recording the location of a feature or fault.	Pothole report; damaged signage, broken glass; vegetation/weeds, overgrown culvert	Required accuracy 5m–10m, but <3m ideal. Cost critical due to high number of units needed (day-to-day field staff activity).
2	Recording the locations of features for data inventory updates, and/or payment considerations.	Moved/replaced signs; reseal lengths; signs, poles, streetlights	Required accuracy <3m, but <1m ideal. Field and office use (post processing). Cost important but efficiencies can be introduced by groups sharing units.

Item	Description	Examples	Comment
3	Finding non-visible features	Relocating duct locations; identifying locations of low skid resistance, roughness, or rutting; crash locations	Required accuracy <3m but <1m ideal. Cost important but efficiencies can be introduced by groups sharing units.
4	Accurate mapping of critical features	Safety hazards like overbridge heights and abutments; in the development of new roads like kerbs, manholes, services; location of reference stations	Required accuracy 0.05m–0.1m (survey accurate). Cost less sensitive as few units required (undertaken by specialist survey staff).
5	Dynamic location mapping	Recording waymarks, faults or features without stopping; location of permanent speed limits (for mobile vehicles)	Required accuracy 3m–10m due to nature of work, varying speeds and uncontrolled conditions.

6 Geographic coverage

This KPI is intended to distinguish technologies that are useable over the vast majority of the Transport Agency's network (albeit recognising that some technologies may have niche applications on parts of the network) from those that are less reliable. A high rating of '>95% coverage, >95% of the time' is intended to identify technologies that will work in all but the most extreme parts of the network. A moderate rating of '90%–95% coverage, 90%–95% of the time' is intended to capture those technologies that will work in most parts of the network but are sufficiently limited in some areas so that an alternative technology will have to be employed for up to 10% of the network. Finally, a low rating of '<90% coverage, <90% of the time' is designed to rank technologies that are applicable to less than 90% of the network, but in other respects may have useful application.

A **weighting of 2** was allocated to this indicator. Geographic coverage is important, but many technologies are equally useful for their ability to fill the gaps where GNSS is not suitable.

7 Future outlook

There was no specific reference to this KPI in the research objectives, but any recommendation should consider the potential costs of future improvements. The ratings attempt to capture this attribute in terms of potential costs to the user. A high rating of 'clear path for future upgrades improving accuracy and utility with little application modification required and full backward compatibility' intends to capture established technologies with a clear path for future applicability where it is expected that any improvements will be relatively inexpensive. A moderate rating of 'expected increase in accuracy, but no clear development path for new technology; moderate application adaption anticipated' is intended to capture technologies with potential for improvement but where development may herald extra costs to implement. A low rating of 'any increase in utility will require extensive adaption of developed applications' is intended to identify technologies that may be expected to develop into useful applications, but at this stage such developments are likely to be expensive either in terms of hardware/firmware or staff training.

As it is difficult to understand the future potential of different technologies, this indicator was given a lower **weighting of 2**.

8 Track record

The introduction of new location technologies may introduce a risk of adopting a technology that appears fit for purpose, but does not prove to deliver value for a variety of reasons. To assess this risk, this KPI is designed to measure whether the technology under consideration has a track record of successful implementation in the transport sector. A high rating of 'commonly used in New Zealand and overseas in network asset management' captures technologies successfully in use in New Zealand and elsewhere for at least some of the common applications (see table 3.2). A moderate rating of 'some existing use in network management overseas' captures technologies not used commonly in New Zealand, but established in overseas transport asset management environments. A low rating 'some examples of use which show promise of adaptability to network asset management' identifies technologies that show promise, but have little or no known current use.

Where evidence of track record exists it is important to measure this, although we have given it a lower **weighting of 2,** as many new technologies will have little track record.

9 Suitability for network contract trial

Any technology recommendations, particularly involving new equipment or software, need to be trialled, preferably within a current state highway contract. The eventual suitability of a technology can be indicated by how easy it is to trial. A high rating of 'pilot studies can be readily set up live in an existing Transport Agency region using existing workers with little disruption to operations' means the technology can be easily trialled in an existing contract situation with little disruption to current operators. A moderate rating of 'pilot study can be set up and run in parallel with an existing Transport Agency region with research staff working alongside existing workers' means the technology can be used in parallel with existing operations by researchers working with existing operators, but with minimal disruption to operations. A low rating of 'pilot study must be modelled by research workers independent of live operations' means the technology shows promise, but because of training or customisation requirements must be trialled independently of current applications.

The ability to trial a new technology reduces the risk and subsequent cost of an unsuitable implementation. This was given a lower **weighting of 2**.

10 Integration with RAMM software

The RAMM database is the current repository of much of New Zealand's road asset data. Thus, it is desirable that a location technology is able to both upload and download datasets in a RAMM-compatible format, without limiting new systems to only record RAMM-related data. A high rating of 'compatible with easy upload/download using existing applications' means users of the technology will face no barriers in accessing RAMM data for location in the field, and will be readily able to download information captured in the field in a format that, when validated, can be used to update the RAMM database. A moderate rating 'some simple application customisation required' was designed to rank technology that requires some customisation to be able to access and download data. A low rating 'significant application development required' captures technologies that show promise, but significant customisation would be required to implement.

Most modern technology can be customised or used with an adaptor to integrate with RAMM where required. This indicator was given a **weighting of 2**.

11 Location derivation

The Transport Agency has a preference for locations expressed in 'absolute' rather than in 'relative' terms. This means coordinates should be expressed in terms of New Zealand Geodetic Datum 2000 (NZGD2000), the official geodetic datum for New Zealand and its offshore islands, and projection New Zealand Transverse Mercator (NZTM). A high rating of 'directly reads and records absolute coordinates and can handle NZTM and other NZGD2000 projections' means NZTM coordinates can be uploaded/downloaded to all devices and manually read off field equipment. Operators need not be aware of any other datum/projection that might be used. A moderate rating ‘directly reads and records absolute coordinates but requires customisation to express in terms of NZGD2000/NZTM’ means that an alternative datum/projection (eg NZGD1949) may be read or recorded, but users are able to reasonably easily convert this to NZTM for data use and sharing. A moderate rating also includes systems that may derive coordinates from short relative measurements in an ‘absolute’ coordinate environment. A low rating of ‘indirectly derives absolute locations from other relative measurements’ refers to a system that only derives absolute coordinates indirectly from relative field measurement.

Most modern technology should be able to handle the translations between different methods for storing location information, so this indicator was given the lowest **weighting of 1**.

12 Suitability as back-up technology

This KPI is aimed at identifying technologies that would be suitable as a back-up if a primary technology fails. Cost is important, as it would be impractical to suggest an expensive technology be maintained only as a back-up. A high rating of ‘readily available to most staff in normal course of events, known technology to staff’ is designed to capture technology that is likely to continue to be available and that field staff will find intuitive to use if their primary location tool fails. A moderate rating of ‘may require some additional low-cost equipment in vehicle, known technology to staff’ identifies technologies that may require some investment but that staff will be able to use with little or no support. A low rating of ‘will require specialist equipment and/or developed applications and training’ includes technologies that have some potential in this area but would require specific additional equipment, development and/or training.

This indicator was given the lowest **weighting of 1** as although back-up technologies are important they cannot act as a primary location technology.

3.2 Technology summary

The literature and technology review in chapter 2 gives a wider description of technologies that are being used or could have potential uses within the transport sector in New Zealand. As explained in the methodology in section 1.4, this larger list of technologies was summarised into a table of individual or bundled technologies for evaluation against the performance indicators listed above. Table 3.3 outlines the technologies that were evaluated, with descriptions and considerations against each one. More information on each of these technologies can also be found in chapter 2.

In terms of the bundled options, there are many other possible combinations of technologies which could be explored, such as the combination of RFID and GPS. We have used an evaluation process that is structured and repeatable so that it can be re-used and updated over time.

Table 3.3 Summarised location technologies

Location technology		Notes
GNSS/ satellite	Consumer grade GNSS	• Includes use of recreational GNSS receivers and smart phones used only to transfer coordinates into some other system • Assumes operator is familiar with basic operation, eg orientation, clear sky • Nominal accuracy 5m–15m • Current use for some basic asset applications

Location technology		Notes
	Embedded consumer grade GNSS (single point positioning)	• Advanced recreational units, smart phones with accessible applications, personal digital assistants, tablets with accessible applications • Assumes operator is familiar with basic operation, eg orientation, clear sky • Upload/download possible and can record attribute information • Nominal accuracy 5m–15m • Currently widely used by some operators in basic asset management
	Basic mapping grade GNSS (single point positioning)	• Includes a range of devices with quality hardware/firmware, including asset applications • Assumes some operator training • Upload/download to asset software • Nominal accuracy 3m–5m • Currently used by some operators in asset management
	Advanced mapping grade GNSS (differential GNSS – code)	• Includes a range of devices with quality hardware/firmware, including asset applications • Assumes operator training and skilled office support • Upload/download to asset software and post-field correction of GNSS measurements • Nominal accuracy 1m–3m (corrected) • Currently used in some overseas and New Zealand applications
	Enhanced mapping grade GNSS (differential GNSS – code)	• Includes a range of devices with quality hardware/firmware, including asset applications. Some internet and or satellite based real-time correction services available. • Assumes operator training and skilled office support • Upload/download to asset software and post-field correction of GNSS measurements (where real-time correction not implemented) • Nominal accuracy 0.5m–1m (corrected) • Some manufacturers have implemented advanced satellite tracking software enabling far greater reliability in 'canyon' situations – both forests and urban
	Survey grade GNSS (differential GNSS – carrier phase)	• Includes a range of single and dual frequency devices. Internet services available for real-time correction for many units. • Assumes skilled operator training and skilled office support • Upload/download to survey software and post-field correction of GNSS measurements (where real-time correction not implemented) • Nominal accuracy 0.1m–0.5m (corrected) • Use restricted to cell phone areas or coverage of local radio bases for real-time application.

Location technology		Notes
Ground based	Tracking systems	• Using passive transponders or codes to relay location information eg RFID, QR codes
	Local area systems	• Wifi, Bluetooth
	Wide area systems	• Mobile telecommunications networks
	GNSS simulation/psuedolites	• Locata
	INS	• Detect the change in an objects position, velocity and orientation • These include IMUs which consist of accelerometers, gyroscopes and magnetometers
	Odometers and trip meters	• Track the distance a vehicle travels in relation to a start point • Often used as an auxiliary sensor to prevent error degradation in INS.
Bundled options	Mobile GIS with imagery and consumer grade GNSS	• Mobile GIS system with accurate imagery and inbuilt GPS • Existing imagery can be leveraged, with cost implications
	Desktop GIS with imagery	• Using ortho photography and GIS or GPS/GNSS for mapping or location of assets • Positioning by trilateration to known points on ortho-rectified images using a tablet application assisted with low-cost GPS/GNSS systems • Existing imagery can be leveraged, with cost implications
	3D desktop GIS with ground based LiDAR and video	• 3D GIS viewer with access to detailed LiDAR point cloud and video along the network.
	Advanced spatial analysis	• Imagery analysis (reflectivity, lidar intensity, camera matching)
	Road asset management systems/geospatial hypermedia	• GIS based viewers combing aerial photography, current asset data and geo-referenced photos and videos to allow asset identification.
	Mobile mapping systems (MMS)	• Fully integrated 3D laser, video, GNSS, IMU and trip meter mounted on a vehicle
	Enhanced mapping grade GNSS with GNSS simulation in areas of low coverage	• Extending GPS/GNSS measurement with IMU technology • Use of laser distance measurement and GPS/GNS location equipment • Accuracy of electronic compass and laser based distance measurement systems • Integrated GPS/GNSS and linear reference measurement • Currently not fully developed for low-cost application

3.3 Results

The results of the location technology evaluation are presented in table 3.4. Each technology was rated against each KPI, as a 1, 2, 3 or 0 (not applicable), based on the KPI descriptions detailed in section 3.1, with a higher value meaning a better fit with the KPIs. The ratings are based on the characteristics of the technology and also informed by the discussions with the steering group in the original project workshop.

In the table, the higher scores are presented in darker shades. Each rating was multiplied by the relevant weighting factor to derive a score out of a total of 132.

Table 3.4 Evaluation location technologies against KPIs

Location technologies *Note:* *Technologies denoted in italics are not currently widely used in New Zealand so will require significant investment.*		**Key performance indicators (weighting factor denoted in parentheses)**												
		Accuracy (10)	**Affordability (10)**	**Set up costs (4)**	**Ease of use by contractors (4)**	**Applicability to common uses(4)**	**Geographic coverage (2)**	**Future outlook (2)**	**Track record (2)**	**Suitability for network contract trial (2)**	**Integration with RAMM software (2)**	**Location derivation (1)**	**Suitability as back-up technology (1)**	**Total (132)**
GNSS	Consumer grade GNSS	1	3	3	3	1	2	2	3	3	1	3	3	**96**
	Embedded consumer grade GNSS	1	2	3	3	1	2	2	3	3	2	3	2	**87**
	Basic mapping grade GNSS	1	1	3	3	1	2	3	3	2	3	3	1	**78**
	Advanced mapping grade GNSS	2	1	3	2	2	2	3	3	2	3	3	1	**88**
	Enhanced mapping grade GNSS	3	1	3	2	2	2	3	3	2	3	3	1	**98**
	Survey grade GNSS	3	1	3	1	3	1	3	3	1	3	3	1	**94**
Ground-based systems	*Tracking systems (RFID)*	*3*	*1*	*1*	*3*	*1*	*1*	*3*	*1*	*1*	*0*	*1*	*1*	**74**
	Local area systems	*1*	*1*	*1*	*2*	*1*	*1*	*2*	*1*	*1*	*0*	*3*	*1*	**50**
	Wide area systems	*1*	*1*	*1*	*2*	*1*	*1*	*2*	*2*	*2*	*0*	*3*	*2*	**55**
	GNSS simulation	*3*	*1*	*1*	*2*	*2*	*1*	*2*	*1*	*3*	*0*	*3*	*1*	**78**
	Inertial navigation systems (INS)	1	1	3	1	1	3	1	2	2	0	1	2	**59**
	Trip meters	2	2	3	2	2	3	1	3	2	1	1	3	**92**
Bundled options	Mobile GIS with imagery and consumer grade GNSS	2	2	2	2	2	1	3	3	2	2	3	2	**91**
	Desktop GIS with imagery	2	2	1	1	1	1	3	3	1	2	3	1	**76**
	3D desktop GIS with ground based LiDAR and video	*3*	*1*	*1*	*1*	*1*	*1*	*2*	*1*	*1*	*1*	*3*	*1*	**68**
	Advanced spatial analysis	0	1	1	1	1	1	0	1	1	0	3	1	**32**
	Geospatial hypermedia/road asset management systems	0	1	1	1	2	1	1	3	1	2	3	1	**46**
	Mobile mapping systems (MMS)	3	1	1	1	2	2	3	3	2	3	3	1	**86**
	Enhanced mapping grade GNSS with GNSS simulation in areas of low coverage	*3*	*1*	*1*	*2*	*2*	*3*	*3*	*3*	*2*	*3*	*3*	*1*	**92**

3.3.1 Factors for consideration

The evaluation method used in this research has some limitations based on the qualitative nature of the analysis and reliance on a limited number of researchers to provide inputs. It should be viewed as an indicative measure of technology suitability and used as a basis for further adaption, updating and application. The points below cover a number of factors for consideration when using these results.

1. The method to evaluate different technologies against a range of indicators based on requirements is a good way to display quantitative results, as shown in table 3.4. Perhaps more importantly, the methodological process ensured that each technology was reviewed against each of the indicators to reduce the risk that a technology was missing some fundamental attribute. Taking this into account, comparing final technology evaluation totals or scores against each other should be done with caution, and a better approach would be to band technologies into groups.
2. The evaluation system developed during this research is one component of this report that the researchers recommend be further developed and updated as an independent table or tool which is flexible and interactive. This would enable users to better evaluate technologies based on the types of work they undertake.
3. Based on point 2 above, a future version of this table could look to pull the 'applicability to common uses' KPI out of the evaluation process and have a separate evaluation process for each of the main uses.

3.3.2 High-performing technologies

When considering all of the technologies available there is some difficulty in presenting any one technology as the answer to all problems. Additionally, some of the technologies are emerging and it is not yet possible for some transport-related industries to make use of these technologies.

This section seeks to provide additional information and explanation around the technologies that performed well against the numerous KPIs outlined above. It has been broken down into two parts: 1) an outline of **current technologies** that performed well against the KPIs, and 2) an outline of **fringe technologies** that performed well against the KPIs. The latter technologies cannot necessarily be implemented in a complete manner at present, but appear to achieve the KPIs, and when widely available could be used to capture spatial information on road-related projects/tasks.

3.3.2.1 Mapping grade GNSS

Mapping grade GNSS receivers are an established method for the capture of existing location information on road infrastructure projects. These receivers are capable of achieving the accuracies desirable for the capture of spatial information for the majority of the Transport Agency's transport assets, with a few locations unable to be measured accurately because of overhead obstructions such as trees, buildings and tunnels. They are also designed for the capture of attributes associated with spatial information and for the electronic transfer of that information into databases and CAD packages.

As outlined in the literature, there are documented uses of mapping grade GNSS for data capture of road information. These have a significant advantage over consumer grade GNSS receivers in that they can provide sufficiently accurate information for meaningful use in GIS databases. In other words, if captured positions were plotted over other GIS data layers, the positions would match up with the data layers. However, mapping grade GNSS are more expensive than consumer grade GNSS technologies. They are also more user friendly than the survey grade GNSS receivers, and the ability to apply differential corrections in real time is becoming increasingly efficient. Post-processed differential corrections are also becoming more accessible and user friendly in the absence of real-time corrections.

Most mapping grade GNSS receivers suitable for data capture of road infrastructure features cost around $2000. However, this is the cheapest standalone device able to meet the desirable accuracy requirements, which is also equipped with a sufficient level of software to enable simple storage of attributes associated with the accurate positions obtained.

Mapping grade GNSS receivers are well suited to contractors' main uses of location technology, with the only exception being the accurate mapping of critical features. This failed because sub-decimetre accuracy is required to map critical features and mapping grade GNSS cannot deliver this level of accuracy. The only device capable of doing this is the survey grade GNSS receiver, which is significantly more expensive.

Mapping grade GNSS receivers were also flagged as having significant future potential around positioning. In the longer term, it is likely these devices will be able to make use of ground-based GNSS simulation systems such as Locata, which will further increase coverage and positioning accuracy. GNSS technologies are also becoming increasingly future proofed, with receivers capable of tracking proposed future satellite signals such as the L2C code on the L2 band, and the L5 signal. Purchasing devices capable of tracking future signals could significantly reduce the potential costs in having to replace a system when technological advances become available. However, as satellites have a reasonably long life (>15 years) it will take some time before any modernisations become viable. For example, the University of Otago's School of Surveying owns devices capable of tracking the L2C code that have been around for 10 years, yet none of their applications or processing make use of the signal today.

Further augmenting this technology with road trip meters, inertial measurement systems, or compass and laser range finders could increase the coverage of the overall system; however, with each additional technology there is another potential source of error to be propagated into the overall positioning accuracy. Additionally, it becomes more difficult and cumbersome for users, thus requiring additional training and increasing the probability of positioning errors.

3.3.2.2 Mobile GIS with accurate imagery and consumer grade GNSS

This method of positioning depends heavily on the resolution and accuracy of imagery data, so is only currently applicable on the parts of the network that have high-quality data. It has not been widely used or tested in the field, so should be used with some caution, or perhaps only implemented after a trial run.

This is a bundled technology package that would make use of a mobile GIS type device with the ability to readily record spatial information and associated attributes. Such a device would have a consumer grade GNSS chip and high accuracy and resolution geo-referenced, ortho-rectified aerial imagery of the entire state highway network. The concept for positioning is that the consumer grade GNSS chip within the device would pan to the approximate positioning location on the aerial imagery where the user could then position the device more accurately by selecting the location of the asset on the aerial imagery. This technique could improve the positioning accuracy to approximately 1m (dependent on the accuracy and resolution of the imagery).

In terms of a balance between affordability and accuracy, this system outperforms all other positioning systems. However, there are significant setup costs and the system would require on-going investment. After the high-resolution imagery has been captured and provided to consultants and contractors with accurate geo-referencing information, the residual cost of purchasing a mobile GIS type device could be as low as $500. A basic tablet device would be capable of providing the necessary platform and consumer grade GNSS possibility. However, it is likely that some basic customisation would be required.

The coverage of this technology would be slightly better than mapping grade GNSS and its positioning accuracy likely to be slightly higher, but it is more subject to gross error by incorrect identification of a point by a user. Training of field staff to use this technology is important as they will need to have experience navigating a map viewer on a tablet device. This technology also has the potential to add other GIS datasets onto the device to aid navigation, and some GIS functionality could also be used to undertake routing and other spatial analysis in the field.

This positioning method could also be used as a backup system for the mapping grade GNSS system outlined above. If the aerial images were all loaded into the mapping grade GNSS device then this technique could be used to assist in positioning.

3.3.3 Promising future technologies

There are numerous technologies or improvements to existing technologies that are not currently fully operational or available. However, these are worth mentioning because they present an opportunity for improved positioning accuracy in the future. Consideration should be given to these technologies when looking at an implementation plan, so that purchases are future proofed against further capital investment at the time they become available.

GNSS simulation (eg Locata) is becoming increasingly common and presents an opportunity for an increase in the coverage and accuracy of GNSS-based positioning in terrain that has low or inconsistent satellite coverage, or currently does not permit usage, by taking advantage of simulated GNSS signals. This could enable GNSS positioning to obtain the required accuracy in problem areas such as tunnels and under tree canopies.

New GNSS signals/codes, like the L5 (signal) and L2C (code), could enable increased positioning accuracy and dependability using lower-cost receivers. For example, if the L2C signal is added to the L2 band, it may be possible to undertake dual frequency positioning using low-cost receivers.

Of the other wireless technologies there is some definite potential for certain parts of the state highway network to set up a local network using technology such as RFID, Bluetooth or Wifi. Unlike the GNSS simulation technology (for example Locata), this would require investment and development of receivers that can read both GNSS and other wireless systems. In addition to the set-up time, there is also a significant cost in setting up and maintaining the physical network.

The ability to utilise 3D point clouds and network imagery derived from MMS, also shows great potential for some asset management purposes. The advantages are that anyone can access and view location information, measure distances and undertake asset valuation and condition assessments from a desktop environment. The obvious disadvantages are that surveys are expensive, would need to be regularly repeated, and the software to manage and interrogate this sort of information is in its infancy. However, for parts of the network that have low or inconsistent GNSS coverage, regular MMS surveys could be a valid option.

4 Implementation roadmap

The technology evaluation in chapter 3 outlines the types of location technologies that best meet current requirements. The New Zealand transport industry will face the on-going challenges of keeping abreast of advances in location technology and integrating appropriate technologies where required. In this section, suggestions for the successful uptake of location technologies are made as part of an implementation roadmap.

The key to increasing the uptake of location technology is shown in figure 4.1. This graphic is overlain on a section of the Auckland upper harbour corridor in 2009.

Figure 4.1 Components to increase the uptake of location technology

The roadmap components are:

1 **On-going research** – initiatives to keep the technology evaluation and lessons learnt as detailed in this research report up to date

2 **Lessons learnt and organisational guidelines** – contributions from representative organisations that have implemented location technology in the past, and similar examples from the international literature

3 **Policy and vision – Transport Agency policy and manuals** to assist with better uptake of location technology

4 **Technology trials** – encouraging and investing in the trialling of promising location technologies.

Each of these four components is described in greater depth below, and specific recommendations are made for the roadmap approach at the end of the section.

4.1 Research

It is evident from the review of technology in chapter 2 that research and development in the field of location technology is on-going, with many new applications on the horizon. There are two main areas outside of transport asset management that are driving location technology research:

1. Location-based services – these refer to technology that enables an organisation to provide services based on the location of a person. This technology is now prevalent in many modern smartphones through applications like Google Maps. Gartner (2013) predicts by 2030 people will feel spatially blind without this technology, which enables them to see who or what is near them, get support, do searches based on the current location, and collect data onsite in an accurate and timely manner.

2. Cooperative intelligent transport systems (C-ITS) – a recent Austroads report (Austroads 2013) refers to C-ITS as 'the use of wireless communications and real-time information sharing between vehicles and roadside infrastructure, which will enable the next generation of applications that improve safety, productivity, efficiency and environmental outcomes for transport systems'.

Research in these areas is helping to direct developments in hardware, software, battery life and mobile computing. It is important that this research is kept current to inform the transport sector. Some potential initiatives for doing so include:

- assigning a specific owner within the Transport Agency to manage updates and potentially undertake further research
- publishing the research on a Transport Agency website, which would allow users to add comments on different sections and indicate potential areas for update. At a regular period (perhaps quarterly) these comments should be reviewed and the sections with the most feedback updated
- publishing the research on a wiki site and allowing approved external users to update and edit the master document
- presenting the research findings at relevant conferences and workshops at regular intervals with an aim to gather feedback on new developments in location technology
- integrating or aligning research with CRCSI where relevant.

4.2 Lessons learnt

A roadmap for the increased uptake of location technology within the transport sector should be informed by lessons learnt from previous implementations of the technology both within New Zealand and globally. A number of interviews were undertaken with organisations that have used and are increasing their use of location technology on New Zealand roads. The learnings arising from these interviews are presented below (refer to appendix B for the interview schedule). International evidence is also considered and the lessons learnt are summarised.

4.2.1 Contractors and consultants to the Transport Agency

A series of interviews were undertaken with a selection of primary nationwide network management contractors and consultants to the Transport Agency: Downer Group and Fulton Hogan (contractors) and

Opus International Consultants Ltd (Opus – consultants). The interviews explored current and potential future use of location technologies, barriers to further uptake of location technologies and lessons learnt from previous company-wide implementation of location or mobile technology, to identify success factors.

Location technologies are primarily used to locate assets and update asset information. They play an important role in resource utilisation and planning around work location and activities, and the safety of staff in remote areas. They are also used to communicate the location of emergency incidents like crashes or natural hazard events that impact on the state highway network. Both Downer and Fulton Hogan use GPS devices with different accuracies for different road network management contracts and activities, ranging from basic low-cost to survey-grade GPS devices. They also use RAMM products extensively, including Pocket RAMM for mobile devices. Often, the specific data collection hardware used by the contractors has associated software that records location data. Both contractors have also been investing in GIS capacity.

Opus uses a range of location technologies, invests in geospatial capacity and develops software applications for particular projects within the transport asset management sector.

4.2.1.1 Potential for increased location technology uptake

Fulton Hogan's focus is to increase uptake of current technology within the company, with the main barrier to this being cost. New technology of interest to Fulton Hogan includes the 3D LiDAR surveys offered by Terralink, aerial imagery linked to accurate GPS locations, video of the state highway network, and improved GPS accuracy, with regard to the shadowing effect in urban areas. However, data size limits the use of some of this technology because it reduces accessibility speed. Accordingly, for 3D LiDAR and video coverage, for example, there is a desire to have access to tools that allow easy interrogation of these datasets. Similarly, Opus has developed applications that stitch the videos together, so field operators are aware of their location on the network and can index the video, while driving, using inbuilt GPS, eg Contour camera hardware and software.

All three organisations recognise the need for photo-referencing and geo-tagging to provide evidence of an asset's condition before and after work is carried out.

Both contractors would like to be more mobile oriented in the field by acquiring more mobile devices and spatial components for electronic daily records. Likewise, they are also interested in enterprise solutions, where multiple business tools are aligned with the company's financial management systems.

Because much of their work is undertaken outside cell phone coverage, contractors would benefit from having the capability to work offline and then resynchronise when in cellular range. This would prevent wasted downtime.

4.2.1.2 Barriers to location technology uptake and effective use

The organisations were asked to identify any perceived or known barriers to location technology uptake or use within their company. The following barriers were identified:

- Costs – company-wide investments in location technology involve significant capital expense and with better accuracy the price increases exponentially. There are also hidden set-up costs when adopting new technology, for example, needing attachments to mount GPS and cameras on vehicles.
- Hardware specifications – some GPS technology and related hardware has failed in the field in terms of readability and durability. Likewise, software such as Pocket RAMM is resource hungry, so tablets and

other mobile devices need to have good processor speed. The minimum specifications of these technologies need to be clear so that inadequate devices are not purchased in the future.

- Initial staff backlash – when technology allowing the location of staff movements to be tracked was first introduced, some staff had privacy concerns. These fears rapidly decreased once they realised the benefits the technology provides, including identifying good performance.
- Blockages from middle management – Downer anticipated that staff would struggle with some of the technology being imposed on them. These fears proved to be unfounded as people already used personal mobile phone technology, and were also given the opportunity to take the new technology home to show their families. Instead, the blockages in uptake were from middle management who, with a 'knowledge is power' attitude, resisted enabling their staff with the new technology. To overcome this barrier before rolling out the technology in other regions, full buy-in was gained from general managers so middle managers did not have any avenues for complaint.
- Internal information technology (IT) issues – internal IT issues include being too rigid to allow software updates to be downloaded, to lacking standardisation across the business. For example, Fulton Hogan and Opus operate more distributed IT systems on the networks they operate, which can lead to a lack of standardisation, but on the other hand can provide a good environment for innovation.
- Client perceptions – in 2005, Downer made a decision to exit historical location referencing using trip meters to focus on GPS technology. Some clients were concerned about the shift from linear referencing to spatial referencing. In particular, there were perceptions that linear referencing provided significantly greater accuracy. Theoretically, linear referencing can be highly accurate, but the ability to achieve that depends on many variables such as tyre pressures and the track of the vehicle. While some critical assets need to be recorded within accuracy of one or two metres, the vast majority to do not need to be that accurate. It was noted that some clients have a tendency to want higher accuracies than necessary. An accurate network model is important for linear referencing whether location information is collected via GPS or trip meters. It is also important for network owners to realise an accurate and up-to-date centreline will improve the ability to accurately reference asset locations.
- Training challenges – the low-end equipment is relatively straight forward, but getting staff up to speed with some of the high-end equipment can be a barrier. The best technology is user friendly, for example the Pocket RAMM populates a lot of information with one click. When the technology is more complicated staff need to be trained to a high degree. However, if the technology is not regularly used, the training often needs to be refreshed or repeated. Change management challenges – initial challenges with technology uptake include acquiring technology with good battery life, and ensuring that staff remembered to charge the devices prior to going out in the field and understand that charging equipment within their vehicle impacts on vehicle battery life.
- Safety risks – driver safety is a real concern when using any device in a vehicle, as it can take their attention away from driving. It is important to assess any new technology that will be used in vehicles and provide appropriate protocols and training.
- Excessive trust in the technology – most of the tools used are about recording activities, not making decisions about activities, but there is a risk that field staff will rely on the technology more than their common sense. The technology can supersede the need for field staff to take notes and it is hard to measure the relevant details that get missed, and what impact this has on the business.

- Downtime during software updates – software updates, something the contractors have no control over, have had and continue to have a substantial impact on productivity. In particular, the timing of updates can render technology temporarily unusable, and sometimes the updates do not work properly.
- Back-up system maintenance – it is still important to factor in the cost of maintaining systems like Terratrip trip meters or hardcopies of map books in company vehicles in anticipation of the rare occasions when other location technology fails.
- Software limitations – the contractors also expressed some frustration with standard off-the-shelf software products used on mobile devices. For example some may only operate on Windows devices when a lot of staff are using mobile Apple or Android devices. Fulton Hogan is exploring options outside the confines of the Windows environment, including open-source software, with the intention of continuing to load data directly into RAMM, but using a different application to access the information so it can be used more widely (similar systems are used by the AMA).

4.2.1.3 Success factors

The contractors were asked to reflect on previous experience in implementing location technology (or any similar mobile technology) within their organisation and identify factors that helped this succeed. The factors identified all related to good process management.

- Dedicated resources – technology uptake is most successful when resources are dedicated to developing and following a process for delivering the technology. For example, Fulton-Hogan's approach for implementing new technology involves a nation-wide team within the company which conducts appraisals and pilot studies to determine which technology is appropriate. The new technology is then introduced in the field and rolled out throughout the company.
- Pilot trials – both contractors always do pilot studies before integrating new technologies into the business. For example, as part of Downer's shift in 2005 to GPS technology, trials were undertaken to determine GPS accuracy along 130km of state highway between National Park and Whanganui. This part of the network has sections of curvilinear road, cuttings and road at the bottom of high ranges. The GPS values were compared with the linear reference point of every sign asset and found to be within +/- 20m, 90%+ of the time. The trial confirmed for Downer that GPS technology provided suitable accuracy for day-to-day operations.
- Provision of training and on-going support – it is valuable to have adequate training and on-going support structure within the business.
- Controlled use of technology – all Downer staff are issued with Apple smartphones with set protocols. Staff are not permitted to install location tools on their cell phones themselves. All software installations are controlled and staff are given the tools they need for the jobs they do.
- Continuous power source – all these technologies require a power source - a simple but important success factor.
- Minimising staff disruption – it is important that business process changes are not implemented at the same time as changes in technology, as staff may feel overwhelmed. In the past, some staff have blamed technology when it was the business process change they were struggling with.

- Good quality assurance (QA) practices – Downer has found QA practices to be important when moving to automated methods. The old linear referencing model goes through a human manual check when being interpreted.
- Other benefits – a spin-off benefit of GPS technology roll-out has been the ability to reward staff who are performing well and also identify some issues such as speeding in work vehicles.

4.2.1.4 Recommendations made by contracting and consulting organisations

The Transport Agency uses a linear location reference management system (LRMS) for its state highway network. Key features of the LRMS for contractors include reference stations (RS), kilometre marker posts (KMPs) and route positions (RPs). RS are marked by signs at approximately 16km intervals at the junction of state highways, territorial regional boundaries, the start of ramps, the end of highways and large roundabouts. KMPs are intermediary markers, occurring at approximately 1km intervals along the network. A RP is the 'address' format for describing a linear position on the network. The LRMS and associated signage and infrastructure is an expensive system to maintain and there is potential to rationalise aspects of the system and place more emphasis on spatial referencing.

While the LRMS is an artificial model of the network, Downer recognises it as being a worthwhile way to report on the location of an asset, particularly for continuous assets such as paving or surfacing that need to be managed and analysed in a linear manner. However, RPs for assets could be generated by software in the field and there are opportunities for signage to be reduced. The RS locations are useful for operators in the field, but the KMPs are not, as they are inaccurate. Likewise, the RP signage on major culverts is not required. If suppliers of in-vehicle location and navigation products, such as TomTom, were provided with access to the LRMS network, accurate distances from markers, posts and the nearest town would be available, reducing the necessity for signage. For the majority of the country, spatial or on the fly referencing would be appropriate, with some RP signage maintained.

Relevant to this research Downer suggested that the Transport Agency lead a shift away from the old technology by informing relevant organisations of their intended approach so organisations could invest in the right technology. This should involve a move towards business-to-business tools, including enterprise data models, universal data exchange protocols, and provision of the Transport Agency's network model as a web service.

The contractors emphasised the value they see in the outputs of the present research and the importance of keeping this work 'live', perhaps with a Wiki to keep it up to date. These results will inform the roading industry and be of benefit to sectors like water, waste water and transport management. It is excellent that LINZ is also involved.

Emphasis was also placed on the need for consistency around the accuracy requirements for capital and maintenance work.

4.2.2 Emergency services

Both the New Zealand Fire Service (NZFS) and New Zealand Police (Police) have small spatial intelligence teams, both with a national role to manage national and operational data. Roles include systems and applications, delivery and support applications, and management of geospatial/GIS systems. The NZFS team also provides support for the National Rural Fire Authority and Search and Rescue.

Both the Police and NZFS use an Intergraph computer aided dispatch system, based on data from Terralink, which acts like a taxi system to direct staff to incidents. The NZP also use an ArcGIS system with limited licences that was developed for the Rugby World Cup. In the longer term, it is likely that only one of these systems will be continued, pending decisions about which 'assets' – staff and/or vehicles – are to be tracked. Frontline staff also carry emergency ArcGIS-based 'Esponder' devices, that can be operated for up to 15 minutes due to battery limitations. Tablets and smartphones (iPads and iPhones) are also coming into use for applications like Google Maps.

The NZFS intelligence suite includes an Esri Enterprise GIS platform and plans for mobile data terminals. GPS capability is deployed on 80% of appliances (fire trucks) to transmit real-time data about appliance location back to headquarters. Personal GPS units to track staff location during large events, as well as search and rescue operations are also being trialled. The NZFS is up to date with developments in location technology and makes use of other organisations, such as the Transport Agency's camera feed technology.

The Police are not currently looking at improving accuracy, but do keep abreast of technology developments and accuracy improvements. Resources are focused on system tools and data use rather than technology to measure data.

4.2.2.1 Potential for increased location technology uptake

Both organisations recognise the potential for increased location technology uptake. Both see scope for the wider use of current technology and the implementation of new technology, in particular, making the most of smart phones, tablets and location tracking (satellite/telemetery) that fits within existing systems.

Both services anticipate a wide scope of use for mobile devices. The main limitations of the current technology are signal problems in urban street canyons and some rural areas. For example, Urban Search and Rescue needs higher accuracy GPS to overcome canyoning and the challenges of working inside buildings. Similarly, higher accuracy location information is required for fighting bush fires. It would also be useful for Police staff in the field to know the locations of other staff and vehicles, particularly during incidents, and to be able to overlay other information such as previous or recent incidents, and nearby addresses of known offenders for similar incidents. Crash investigators need higher accuracy GPS. A web-based incident reporting system would also be valuable.

4.2.2.2 Barriers to location technology uptake and effective use

Both services experience historical barriers to technology uptake. For the NZFS this is a cultural barrier due to an aging workforce, but technology is now part of everyday life so the barriers are coming down. For the Police, there is wariness due to previous major technology projects that did not experience smooth implementation.

Staff capability and training needs are barriers to the adoption of some technologies.

For the NZFS, cost is now less of a barrier as technology becomes cheaper. The size of the units is a limitation, but new technology is increasingly more compact. There are also political barriers imposed by the union due to 'big brother' perceptions.

From the perspective of the Police, the main limitations are budgetary (including equipment and training costs) and political (direction/policy/strategy) as well as swiftly changing technology. Also, any technology used in Police vehicles and by officers must not interfere with other devices like speed radar and communications.

4.2.2.3 Success factors

The services identified the following success factors:

- Select technology that meets business needs, has a wide scope of use, is easy to upgrade, delivers quick response times, and has a good track record and no known failures.
- Choose technology that is easy to use and flexible because both organisations have a variety of skill sets.
- Adopt technology that can be easily integrated into existing systems.
- Ensure user (staff) and stakeholder engagement, at all levels, from frontline to communications, as well as for policy and strategy.
- Ensure coordination with other emergency services (the Police and NZFS have worked together on development of location technology) and also with other roading groups.
- Have a plan for transitioning the new technology into the business.

4.2.3 RAMM Software Limited (RSL)

The development of Road Asset Management and Maintenance (RAMM) software is driven by client requirements. Pocket RAMM is a mobile tool which is used for updating asset information, programming work, completing and claiming for jobs. Most contractors place emphasis on using Pocket RAMM for programming work or jobs rather than updating asset information.

Pocket RAMM itself is not a location technology but requires the device it is installed on to be GPS enabled. In the past it has been used mainly for job management, as high-accuracy GPS is considered too expensive. The addition of high-accuracy and up-to-date imagery would allow more accurate data capture in the field. Data size can be an issue with imagery, so there is potential to use the Transport Agency's imagery service available through Koordinates Ltd.

The hardware configuration for RAMM software is Windows 7 and 8, with on-board GPS, but there is no post-processing of GPS data. RAMM is not compatible with Apple or Android platforms.

4.2.3.1 Barriers to location technology uptake

From RSL's perspective, training requirements are the greatest barrier to the uptake of new RAMM products by users, though RSL does provide training services to some contractors. Additional barriers include the cost-conscious nature of some clients, and the tendency for consultants to overlook existing products in demonstrating their own point of difference.

4.2.3.2 Success factors

The successful implementation of new technology is enhanced by managers who are committed to training staff in its use. It would also be beneficial for data owners to audit contractors and thereby ensure that data is managed to an appropriate standard.

4.2.4 International evidence

A review of the international literature revealed specific examples and recommendations concerning the implementation of location technology, which echo the experiences of the industry stakeholders interviewed. The key theme is the importance of having good organisational guidelines for staff training and the use of technology. Without such guidelines, there is a risk that staff are given new tools without appropriate training and lack knowledge on how the technology works. An additional risk is that field staff can put too much faith in new technology, and are less likely to self-check the location measurements they are getting. These sentiments are outlined in the *Guidelines for the use of GNSS in surveying and mapping* (Royal Institution of Chartered Surveyors 2010), which recommends that for high-accuracy GNSS surveying the surveyors involved in fieldwork and survey processing should be formally trained with the particular equipment they are using, have had formal training in GNSS theory, and some years' experience in the use of GNSS in land surveying.

The Location Technology Management Plan implemented by the Louisiana DOTD in 2012 (Barnett et al 2012) was initiated because GPS had been adopted by many different sections in the DOTD, without uniform standards for accuracy, operation, hardware, or software. The goal of the project was to create a plan to guide the use of GPS technology within the department. Some of the key recommendations arising from this report included the need to:

- form a GPS oversight committee within DOTD, with representatives from different sections
- establish a GPS coordinator position
- agree on GPS units and purchase these in bulk
- create and test menu systems for data collection
- implement training classes in the basic concepts of GPS.

The North Carolina Department of Transportation went through a similar location technology upgrade process (Edgerton 2009) to enable work crews to use GPS-enabled personal digital assistants (PDAs) in the field for job management. Roadblocks to the roll-out of this plan included lack of funding to purchase GPS units of the desired accuracy. Nevertheless, the implementation was highly successful and led to a number of recommendations, including:

- Smaller handheld devices seemed to be preferred but it was recommended not to focus on one particular brand of PDA, but rather allow the possibility of having multiple styles of PDA which all operate within the same architecture.
- In-built GPS can mitigate some start-up problems found when trying to link to an external GPS using Bluetooth.
- The ability to enter route and mile point data by hand should be retained for use in cases where GPS readings are not attainable.
- When using lower accuracy GPS, it is useful for the operator to enter the route number, especially at intersections.
- Executive support of the proposed upgrade of GPS technology is important, and for similar efforts has historically been a predictor of employee acceptance.

4.3 Additional organisational guidelines for investment in new technology

Achieving a return on investment is important when investing in new technology. In particular organisational investment in emerging technologies, such as those covered in this research, requires careful consideration and preparation. In this section we list some of the key factors which may improve the outcomes from investment in new technology.

4.3.1.1 Agility

Of greatest importance is the ability for an organisation to easily adapt its processes and resources as new technologies emerge. Recent research into organisational investments in IT by the INSEAD Business School (INSEAD eLab 2013) describes this well:

> *[New investments] must sit on top of mature, standardised platforms. Being agile and competitive doesn't mean being the quickest. It means always being able to be quick. The secret is a mature platform and avoiding the creation of 'infrastructure spaghetti' in the rush to adopt the latest tools.*

The important point from this quote is that for an organisation to be agile and able to easily uptake new technologies, it is hugely beneficial for it to have a mature, organised IT platform with access to both technical experts and good management. This research from the INSEAD showed that return on investment is better when organisations have a mature platform in place.

On top of this, it is important for an organisation to accept that small investments in technologies that lead nowhere are an acceptable part of investing in new technology and should be budgeted for. The critical point here is that these investments are not treated as mistakes, but as learning processes. Project managers leading these implementations should be strongly encouraged to pull out quickly from an implementation if it is not working. To allow this to happen, technology should be trialled first and reviewed at an early stage (~5%) of a project, before continuing with an implementation.

4.3.1.2 Alignment within an organisation and the wider industry

It is also important to be mindful of the wider organisational IT and geospatial strategy and resources before making a specific investment, especially for the following:

- GIS software investments
- available IT and geospatial staff resources
- disk space and access to good back-up systems.

Being aware of wider industry strategies and resources is also important. Relevant examples include the Transport Agency’s geospatial strategy and other asset management guidelines and standards. There is a lower risk in aligning investments in location technology with the industry, but there are also times when investing in a new unproven technology may prove beneficial if the rest of the industry also moves in this direction later. This approach comes with an obvious higher risk if the technology is a dead end.

Of course the type of investment is completely dependent on the scale and type of project for which location technology is to be used. If it is a small or short-term one-off project, then investing in something non-standard and perhaps even customising a technology to suit that particular use is acceptable. For a larger on-going project, with inevitable staff turnover, a better choice may be to use standard technology that can continue to be supported.

4.3.1.3 Measuring costs and returns

To better understand how the implementation of new location technology within an organisation is proceeding, it is important to understand the costs and returns. This involves tracking and measuring the main costs in terms of labour and materials and also where the returns in terms of efficiencies, better quality information and marketing potential are being generated.

These types of measures should collect both the quantitative values in terms of expenditure, cost savings and revenue where it can be allocated to a specific technology, but also the more qualitative feedback – both positive and negative – which may come from staff using the technology, or other staff or clients who are using the outputs. Without having a good understanding of this information, it is difficult to know which areas require more investment (training, software upgrades etc), or whether the technology is not meeting requirements and should be discarded immediately.

4.4 Policy and vision

The Transport Agency can help to enable the implementation of location technology by its contractors and consultants through stipulating clear accuracy requirements, providing technology guidance (including this report) and certification systems, and rewarding good track record. This will show that location accuracy and quality is important and is a considered part of any contract. In addition, communicating a clear vision on how the Transport Agency expects its providers to be working in the future is important.

4.4.1 Policy

There are currently two key documents that outline how location technology should be used on the New Zealand state highway network: the *State highway database operations manual* (SHDOM) (NZ Transport Agency 2009) and the *Location referencing management system (LRMS) manual* (NZ Transport Agency 2004). The SHDOM is the main manual for the Transport Agency's asset management. In terms of location technology specifications, appendix 6 of SHDOM is the *Inventory collection manual* and gives an overview of trip meter calibration and potential use of GPS tools, with some discussion on limitations. Appendix 6 also contains information on accuracy requirements for different assets. The LRMS manual describes the system for accurately and consistently locating or referencing positions on the state highway network. This system is made up of physical reference stations, established RPs and KMPs. The manual also explains the accuracy requirements to update these positions. In addition, there are other manuals that provide some guidance regarding the accuracy of location data, including the *AustRoads guide to asset management* (Austroads 2009), in particular Part 5a Inventory, and the *International infrastructure management manual* (New Zealand Asset Management Support 2011).

There are three distinct options for encouraging the use of location technology:

1 Identify suitable technology bundles for different projects and require providers to use these methods. This has the advantage of all providers using the same technology and delivering consistent outputs. However, it may meet resistance due to the costs involved, and also requires investment to maintain an understanding of the best technology for each project. Another key limitation of this approach is lack of flexibility as technologies change.

2 Specify location technology requirements, then tender every three to five years for the provision of location-based technologies that meet these specifications, and require all contractors and consultants to use the provided technologies. The benefits of this approach will be good competition and innovation at tender time and a standard for technology use. However, in between these periods there is danger of lack of innovation, and this approach also requires investment by providers in a specific technology.

3 Rather than prescribe specific technologies for contractors and consultants to use, provide a clear definition of the accuracy requirements for particular highway assets and projects. It is then up to the provider to find the right location technology tool or partner with the right technology company to provide information to the required level of accuracy. The benefit of this approach is that it allows the Transport Agency to focus on providing clear guidance and requirements while giving the industry the freedom to use location technology most suited to a project. This approach is the most practical, but will require surveillance/auditing of incoming data and certifications to maintain integrity.

For any of the above approaches, a new document clearly stating accuracy requirements could be developed or the requirements could be incorporated into the next release of the SHDOM. It is also important that relevant requests for tender, information or proposals state these requirements and that bids are assessed using these attributes. In addition, a certification system could be introduced that enables an external provider to go through a formal process to become certified as a location information provider. This would give confidence that a provider is using the right location technology, has appropriately trained staff and good succession planning in place.

4.4.2 Vision

It is important that there is a clear vision of how location technology is to be used in the next 5, 10 or 20 years. This vision will obviously have to adapt to changes in technology, but it will give providers a clear message on what they should be aiming for. This may influence the investment decisions both in training and recruitment that providers are making right now. This vision may contain the following key elements:

1 Set **clear accuracy requirements** and indicate how these might change the future.

2 Clearly state that there is a strong preference for location information to be collected with **absolute measurement** systems (GNSS) rather than relative techniques like trip meters.

3 Support a **culture change** within the industry that places more emphasis on the value of accurate and accessible spatial information. The Enterprise Geospatial Capability programme currently underway within the Transport Agency is an example of this change.

4 Clearly communicate any changes to **the LRMS system** and what this might mean for providers to avoid misinterpretation. Even though there is a move towards absolute measurement, this does not mean the LRMS system is unimportant.

5 Support a more **spatially enabled workforce** and look to assist with suitable training programmes and conferences.

Where possible this vision should also be aligned with relevant research and development at the CRCSI. In particular one of the strategic objectives of the CRCSI is a national precise positioning programme for Australia (CRCSI 2013b). Currently New Zealand has representation with the CRCSI through LINZ, and there could be benefit in extending the support and consequently enhance the relationship.

4.5 Technology trials

One of the KPMs mentioned in chapter 3 is that technology should be trialled within a New Zealand context before it is more widely implemented. In both the overseas literature and our engagement process within New Zealand, there was recognition that the trialling of new technology is important. The trialling of new location technology already takes place within many organisations that provide services to the Transport Agency, and also within the Transport Agency itself. Factors to enhance the usefulness of technology trials include:

1. **Appointing skilled staff to manage technology trials.** Organisations need to invest in these staff to select the right technologies to trial, set the elements of the technology to investigate, measure technology performance and report back on the results in the context of the wider organisation. Organisations like the AMA have made this investment and through the Information and Data Management team have undertaken a number of robust trials. Both Fulton Hogan and Downer recruit staff to help improve the use of geospatial tools and data. One way to encourage geospatial investment is to assess track record and staff skills in any tendering process, and to provide a certification system as described in chapter 4.4.
2. **Encouraging innovation within current or future projects**. Innovation is a measurable performance area for teams at the AMA, providing a focus in team meetings and discussions to think of ways to do things differently or more efficiently. Trialling new ideas is part of the innovation process. More weighting could be put on innovation processes and actual innovations developed when evaluating bids. The idea is to encourage organisations to look at options for doing things better and not to change what they are doing just to tick a box.
3. **Working within current projects or identifying future options to encourage a specific location technology trial.** This could either be a separate trial project, or working with a current or future asset management or capital project to look at options for trialling a new location technology. It could involve additional work or a variation to a contract if there is a significant cost or risk to trial something new. Alternatively, the Transport Agency could support an organisation-led trial through providing feedback and/or assistance.

In summary, one of the Transport Agency's roles is to foster and encourage innovation and the use of new location technology by its providers. Cost will always be a factor when an organisation is looking to undertake any work that requires this sort of technology, so anything the Transport Agency can do to influence an organisation to make an investment is important. Informing the industry on its strategic intentions would also be beneficial so that there is some alignment. The Transport Agency's geospatial strategy is an example of this and a document outlining a vision for the industry in 5, 10 or 20 years would also be advantageous.

5 Conclusions and recommendations

The use of location technology within the land transport sector of New Zealand is not new. Surveyors and engineers have used a variety of methods since the country's transport infrastructure was first developed to locate themselves and assets on the network. However, location technology is rapidly evolving and becoming more integrated with many other aspects of daily life. This could be finding out how close the next bus or train is, using a smartphone to find the closest café, or finding the shortest route to drive between two towns.

With the arrival of GPS, GIS and mobile computing, the ability to collect location information in the field, manage this information and analyse it has rapidly increased, potentially faster than the transport industry has been able to implement. This research will help bridge the gap between the location technology that is currently and soon to be available, and the requirements and experiences of people working in the transport and related industries.

To bridge this gap, a workshop with the Transport Agency and a number of key stakeholders was held to better understand industry requirements for location technology. Secondly, a review of literature and technology was carried out and lastly engagement was undertaken with a number of key technology providers and users to understand more about the technology they use and the lessons learnt from implementing new technology.

Below are the key findings and insights from the research, with some brief elaboration.

- **Conclusion 1:** Based on consultation and engagement undertaken on this project a set of KPIs was developed, which represents the location technology requirements of Transport Agency key providers, primarily contractors. These requirements showed a preference for accuracy, affordability and ease of use.

  Recommendation 1: Update these requirements at regular intervals.

- **Conclusion 2:** The literature and technology review process highlighted the considerable amount of on-going research into location technology methods and applications.

  Recommendation 2: Ensure this research report, or elements of it, is a live document with regular updates planned.

- **Conclusion 3:** The evaluation process highlighted a number of technology bundles that showed good potential. These include mapping grade GNSS and consumer grade GNSS augmented with mobile GIS and accurate aerial imagery.

  Recommendation 3: Develop limited trials to better understand how some of the evaluated technologies, in particular the two mentioned above, could be and are being used by roading contractors.

- **Conclusion 4:** The evaluation process also highlighted many promising future technologies which are likely to be useful in the near future (one to five years). These include GNSS augmented with Locata type ground-based constellations, GNSS complemented with the use of local area wireless networks like RFID tags, Bluetooth or Wifi in areas with low GNSS coverage, and the use of ground-based LiDAR surveys with imagery in a 3D desktop environment.

Recommendation 4.1: Monitor the potential of these promising future technologies for trialling on a network or capital contract in the near future.

Recommendation 4.2: Consider partnership with CRCSI, or with one of the existing New Zealand CRCSI partners, such as LINZ.

- **Conclusion 5:** Based on our consultation with key users of location technology and international literature we uncovered a number of important elements to a successful implementation of location technology. These include upper management buy-in to the process, training on the appropriate use of the technology, organisational guidelines on the use of technology, safety assessment for in-vehicle use, awareness of staff privacy issues, pilot trials and dedicated staff to manage the use of the technology. Other guidelines include ensuring the business has a mature IT platform, measuring the return on investment and alignment with the wider industry.

  Recommendation 5: Draw on these lessons when updating Transport Agency manuals (see below).

- **Conclusion 6:** There is currently little guidance or provision of accuracy requirements for the use of location technology by contractors and consultants. The most relevant documents are the *State highway and database operations manual* (SHDOM) and the LRMS manual. To be successful, the use of new technologies requires clear guidance.

  Recommendation 6.1: Develop a new guideline for the appropriate use of location technology or include a new section in the next update of the SHDOM manual. In addition, clearly state in relevant requests for proposals and tenders that these guidelines and standards are to be followed. To further enhance the use of appropriate location technology and new innovations, provide clear guidance and requirements to enable the industry to choose the best tool for the job.

  Recommendation 6.2: Develop a certification system for contractors and consultants working on the state highway network. This certification would acknowledge that a provider is aware of modern location technology, has skilled staff, a good track record and has been on a training session. This certification would likely fit within a current certification system such as RAMM accreditation.

  Recommendation 6.3: Provide a clear vision of where the industry could be in 5, 10 and 20 years. This will allow providers to align with this strategy where possible. This vision may include references to accuracy requirements, preference for absolute referencing, supporting a culture change and a spatially enabled workforce.

To provide some wider context on the potential value of location technology to the economy, New Zealand's broader spatial information industry was estimated to add $1.2 billion of value in 2008 (ACIL Tasmin 2009). Improving the spatial data infrastructure, thereby enabling better use of location technology, was estimated to add a further $481 million of value-added output to the economy. Informed and appropriate use of location technology, as discussed in this report, will lead to more accurate and accessible spatial data.

6 Bibliography

Abo-Zahhad, M, SM Ahmed and M Mourad (2012) Hybrid uplink-time difference of arrival and assisted—GPS positioning technique. *International Journal of Communications, Network and System Sciences 5*, no.6: 303–312.

ACIL Tasman (2009) *Spatial information in the New Zealand economy: realising productivity gains*. Prepared for Land Information New Zealand, Department of Conservation, and Ministry of Economic Development.

Aguilar, MA, FJ Aguilar, F Agüera, and JA Sánchez (2007) Geometric accuracy assessment of QuickBird basic imagery using different operational approaches. *Photogrammetric Engineering & Remote Sensing 73,* no.12: 1321–1332.

Alakus, R (2009) Developing spatial asset management and maintenance processes for roads and pavements. *Journal of Public Works and Infrastructure 2*, no.2: 117–129.

Al-Holou, N, T Pilutti, M Paulik and F Ibrahim (2005) Accurate INS position solution during GPS outages or degraded GPS. *Vehicle System Dynamics 43*, no.9: 633–652.

Alnaqbia, A and A El-Rabbanya (2010). Precise GPS positioning with low-cost single-frequency system in multipath environment. *Journal of Navigation 63*, no.2: 301–312.

Arnold, LL and PA Zandbergen (2011) Positional accuracy of the wide area augmentation system in consumer-grade GPS units. *Computers and Geosciences 37*, no.7: 883–892.

Artes, F and L Nastro (2005) Applanix POS LV 200: *Generating continuous position accuracy in the absence of GPS reception* (technical report). Richmond Hill, ON, Canada: Applanix.

Austroads (2009) *Guide to asset management.* 2nd ed. Sydney, NSW: Austroads.

Austroads (2013) Vehicle positioning for C-ITS in Australia (background document). *Austroads research report AP-R431-13*. 88pp.

Austroads (2013). Emerging digital mapping requirements for C-ITS. *Austroads Research Report AP-R432-13*.

Awange, JL (2012) *Environmental monitoring using GNSS*. Springer.

Barazzetti, L, MA Brovelli and L Valentini (2010) LiDAR digital building models for true orthophoto generation. *Applied Geomatics 2*, no.4:187–196.

Barnett, J, J Harrison and K Steede-Terry (2012) DOTD GPS technology management plan. *Louisiana Transportation Research Center project no.11–2P.*

Bassani M, A Lingua, M Piras, M De Agostino, G Marinelli and G Petrini (2012) Alignment data collection of highways using mobile mapping and image analysis techniques. In *Proceedings Transportation Research Board Meeting*, Washington DC, January 2012.

Beauregard, S and H Haas (2006) Pedestrian dead reckoning: a basis for personal positioning. In *Proceedings Positioning, Navigation and Communication Workshop*, Hannover, Germany, March 2006.

Beca Infrastructure Ltd (2011) *Bluetooth deployment – Puhoi to Warkworth pilot study*. Report for the NZ Transport Agency. Accessed 11 September 2013. www.bliptrack.com/fileadmin/pdf/traffic/NZ1-4002843-Bluetooth%20Deployment%20-%20Puhoi%20to%20Warkworth.pdf

Bekkelien, A (2012) *Bluetooth indoor positioning*. Master of Computer Science thesis. Geneva, Switzerland: University of Geneva.

Bensky, A (2007) *Wireless positioning technologies and applications*. Norwood, MA, USA: Artech House. 305pp.

Bevly, DM (2004) GPS: a low cost velocity sensor for correcting inertial sensor errors on ground vehicles. *Journal of Dynamic Systems Measurement and Control 126*, no.2: 255–264.

Biagi, L and S Caldera (2011) The automation of permanent networks monitoring: remarks and case studies. *Applied Geomatics 3*, no.3: 137–152.

Biagioni, J and J Eriksson (2012) Inferring road maps from GPS traces: survey and comparative evaluation. *Transportation Research Record: Journal of the Transportation Research Board 2291*: 61–71.

Bigham, JM, S Kang, S Kho, D Kim and SH Park (2011) Geocoding vehicle collisions on Korean expressways based on postmile referencing. *KSCE Journal of Civil Engineering 15*, no.8: 1435–1441.

Bilke, A and J Sieck (2013) Using the magnetic field for indoor localisation on a mobile phone. Pp 195–208 in *Progress in location-based services*. JM Krisp (Ed). Berlin Heidelberg: Springer-Verlag.

Black, D and R Beggs (2012) Real-time arterial travel time using GPS fleet data. In *Proceedings of the Intelligent Transportation Society of America 22nd Annual Meeting & Exposition*. National Harbor, Maryland: May 2012.

Buchli, B, F Sutton and J Beutel (2012) GPS-equipped wireless sensor network node for high-accuracy positioning applications. Pp.179–195 in *Proceedings of the 9th European conference on Wireless Sensor Networks.* Trento, Italy: February 2012.

Burlarley-Hyland, A, B Toothill and A Das (2012) Use of automatic vehicle location systems, geographic information systems, and global positioning systems to increase efficiencies and decrease cost in maintenance management. *Transportation Research Circular E-C163: Maintenance management*: 46–54.

Burnham, T, M Vasudevan and A Tewfik (2010) Development of a global positioning system-based vehicle tracking system for the Minnesota Road Research Facility. *Transportation Research Record: Journal of the Transportation Research Board 2153*: 153–161.

Cai, H and W Rasdorf (2008) Modeling road centerlines and predicting lengths in 3-D using LIDAR point cloud and planimetric road centerline data. *Computer-Aided Civil and Infrastructure Engineering 23*, no.3: 157–173.

Cai, Y, P Cheng, X Meng, W Tang and C Shi (2011) Using network RTK corrections and low-cost GPS receiver for precise mass market positioning and navigation applications. Pp 345–349 in *Proceedings of the IEEE Intelligent Vehicles Symposium (IV),* Baden-Baden, Germany: June 2011.

Cambridge Systematics Inc (2009) Market research for Idaho Transportation Department linear referencing system. *Report prepared for the Idaho Transportation Department* . Cambridge, Massachusetts: Cambridge Systematics, Inc.

Chan, W, Y Xu, X Ding, Y Xiong and W Dai (2006) Assessment of dynamic measurement accuracy of GPS in three directions. *Journal of Surveying Engineering 132*:108–117.

Chase, RT, BM Williams, NM Rouphail and S Kim (2012). Comparative evaluation of reported speeds from corresponding fixed-point and probe-based detection systems. *Transportation Research Record: Journal of the Transportation Research Board 2308*: 110–119.

Chen, D, S Tsai, KH Kim, C Hsu, JP Singh and B Girod (2010) Low-cost asset tracking using location-aware camera phones. In *Proceedings SPIE 7798, Applications of Digital Image Processing XXXIII*. San Diego, CA, September 2010.

Chu T, N Guo, S Backén and D Akos (2012) Monocular camera/IMU/GNSS integration for ground vehicle navigation in challenging GNSS environments. *Sensors 12*: 3162–3185.

Clarke, RA and MR Wigan (2011) You are where you have been: the privacy implications of location and tracking technologies. *The Journal of Location Based Services 5*, no.3–4: 138–155.

CRCSI (2013a) *Achievements report 2011–12*. Cooperative Research Centre for Spatial Information. Accessed 11 September 2013. www.crcsi.com.au/getattachment/f17b97ec-6a09-4d8f-a43a-5f6450bd904f/CRCSI-Achievements-Report-2011-12.aspx

CRCSI (2013b) *Strategic plan (approved 23 Feb 2103).* Cooperative Research Centre for Spatial Information. Accessed 11 September 2013. www.crcsi.com.au/Documents/_Administration/STRATEGIC-PLAN.aspx

De Agostino, M, A Lingua, F Nex and M Piras (2010) GIMPhI: A novel vision-based navigation approach for low cost MMS. In *Proceedings of the Position Location and Navigation Symposium (PLANS),* May 2010.

de la Garza, JM, NJ Yates and AG Arrington (2009) Improving highway asset management with RFID technology. In *Proceedings 26th CIBW078 Conference*, Istanbul, Turkey, October 2009: Pp163–169.

Dow, JM, RE Neilan, and C Rizos (2009). The international GNSS service in a changing landscape of global navigation satellite systems. *Journal of Geodesy 83*, no.3: 191–198.

Dziadak, K, B Kumar and J Sommerville (2009) Model for the 3D location of buried assets based on RFID technology. *Journal of Computing in Civil Engineering 23*:148–159.

Edgerton, J, C Pilson and M Whitley (2009) Use of PDAs to capture field data for input in North Carolina's maintenance management system. *Transportation research circular E-C135: maintenance management:* pp177–190.

Emery, W (2012) Remote sensing of roads and highways in Colorado: large-area road-surface quality and land-cover classification using very-high spatial resolution aerial and satellite data. *Quarterly progress report #1 (08/15/2012 to 12/31/2012).* 18pp.

Flor, A, N Pinter and JWF Remo (2011) The ups and downs of levees: GPS-based change detection, Middle Mississippi River USA. *Geology 39*:55–58.

Fontaine, MD and BL Smith (2004) Improving the effectiveness of traffic monitoring based on wireless location technology. In *Proceedings of the Virginia Transportation Research Council,* December 2004.

Fontaine, MD and BL Smith (2007) Investigation of the performance of wireless location technology-based traffic monitoring systems. *Journal of Transportation Engineering 133*, no.3: 157–165

Fontaine, MD, BL Smith, AR Hendricks and WT Scherer (2007) Wireless location technology–based traffic monitoring: preliminary recommendations to transportation agencies based on synthesis of experience and simulation results. *Transportation Research Record: Journal of the Transportation Research Board, 1993*: 51–58.

Gakstatter, E (2010) What's going to happen when high-accuracy GPS is cheap? Accessed 1 May 2013. *www.gpsworld.com/surveywhats-going-happen-when-high-accuracy-gps-cheap-10024/*.

Gartner, G (2013) Location Matters LBS:2030. PpXXV–XXIII in *Progress in location-based services: lecture notes in geoinformation and cartography*. JM Krisp (Ed). Berlin Heidelberg: Springer-Verlag.

Geomatic Technologies (2013) *Case study of Greater Geelong, Victoria Australia*. Southbank, Victoria: Geomatic Technologies.

Gianni, D, J Fuchs, P De Simone and M Lisi (2013). A modelling language to support the interoperability of global navigation satellite systems. *GPS Solutions 17*, no.2: 175–198.

Glennie, C (2007). A kinematic terrestrial LIDAR scanning system. Pp1625–1630 in *Proceedings of the 20th International Technical Meeting of the Satellite Division of The Institute of Navigation.* Fort Worth, TX, September 2007.

Godha, S (2006) Performance evaluation of a low cost DGPS MEMS-based IMU integrated with DGPS for land vehicle navigation application. *University of Calgary geomatics engineering report no. 20239* and *MSc thesis*. 230pp.

Goodchild, MF (2000) GIS and transportation: status and challenges. *GeoInformatica 4*: 127–13.

Hayati, S and M Mirmirani (1985) Improving the absolute positioning accuracy of robot manipulators. *Journal of Robotic Systems 2*, no.4: 397–413.

He, Q and L Head (2010) Lane level vehicle positioning with low cost GPS. In *Proceedings of the 89th Annual Meeting of the Transportation Research Board,* Washington DC, January 2010.

Herold, M, M Gardner, V Noronha and D Roberts (2003) *Spectrometry and hyperspectral remote sensing of urban road infrastructure*. Accessed 29 April 2013. http://satjournal.tcom.ohiou.edu/pdf/herold.pdf

Herrera, JC, DB Work, R Herring, X Ban and AM Bayen (2009) Evaluation of traffic data obtained via GPS-enabled mobile phones: the mobile century field experiment. *Working Paper UCB-ITS-VWP-2009-8,* Institute of Transportation Studies (UCB), UC Berkeley.

Hong, S and AP Vonderohe (2011) Uncertainty issues in integrating Geographic Information Systems and the Global Positioning System for transportation. *Transportation Research Record: Journal of the Transportation Research Board 2215*: 50–58.

Hounsell NB, BP Shrestha and A Wong (2012) Data management and applications in a world-leading bus fleet. *Transportation Research Part C, Emerging technologies 22*: 76–87.

INSEAD eLab (2013) Building competitiveness and business performance with ICT: how investments in new technologies can make companies more competitive. Accessed 12 May 2013. *https://ec.europa.eu/digital-agenda/en/news/building-competitiveness-and-business-performance-ict*

Ivetic, D and S Mihic (2009). *Data structures for road condition AVI file video augmentation*. DAAAM International Scientific Book. 117pp.

Jang, J and N Baik (2012). Diagnosing hazardous road surface conditions through probe vehicle as mobile sensing platform. In *Proceedings Transportation Research Board*, Coralville, Iowa, April–May 2012.

Jeffrey, C (2010) *An introduction to GNSS: GPS, GLONASS, Galileo and other global navigation satellite systems*. Alberta, Canada: NovAtel.

Kelley J and H Chen (2011) Harmonisation of location referencing for related data collection. *Austroads project AT1484*. 54pp.

Kim, T J and K Choi (2012) GIS for transportation. Pps503–521 in *Springer handbook of geographic information.* W Kresse and DM Danko (Eds). Berlin Heidelberg: Springer-Verlag.

Kong, Y and X Liu (2011) A web-based geographic hypermedia system: data model, system design and prototype applications. Accessed 21 April 2013. *www.paper.edu.cn/en_releasepaper/content/4410150*

Koprowski, Y (2012) Bluetooth vs. GPS travel time data. *Institute of Transportation Engineers Technical Conference and Exhibit*. Pasadena CA, March 2012.

Kwanmuang, S, L Ojeda and J Borenstein (2011) Magnetometer-enhanced personal locator for tunnels and GPS-denied outdoor environments. In *Proceedings of SPIE 8019*, Orlando, Florida, USA, June 2011.

Langridge, RM (2011) Precise mapping of near-field fault deformation in New Zealand using LiDAR technology : final report : hazards platform contestable fund. *GNS Science report, 2011/44:* Lower Hutt, NZ.

Latta, J (2009) Coverage you don’t outrun: wide area GPS networks provide data 24/7 – and you’re never out of range. *Better Roads 79*, no.3: 8–10, 13.

Lee, J, D Yun and J Sung (2012) Test of global positioning system–inertial measurement unit performance for surveying road alignment. *Journal of the Transportation Research Board*, no. 2282: 3–13.

Li, B and P Teunissen (2012) Real-time kinematic positioning using fused data from multiple GNSS antennas. In *Proceedings of the 15th International Conference of Information Fusion*, July 2012, pp933–937.

Malinovskiy, Y and Y Wang (2012) Pedestrian travel pattern discovery using mobile bluetooth sensors. In *Proceedings of the Transportation Research Board*, Washington, DC, January 2012.

Marshall, P (2007) Highway maintenance: Florida field system combines an asset database with GPS data to reduce the toll of turnpike management. *Government Computer News 26*, no.23: 10.

Mattern, N and G Wanielik (2011) Vehicle localization in urban environments using feature maps and aerial images. In *Proceedings of the 14th International IEEE Conference on Intelligent Transportation Systems* (ITSC), Washington, DC, October 2011. Pp1027–1032.

Meijer, A, B van Arem, M Salomons, P Krootjes and N Cohn (2012) Probe data from consumer GPS navigation devices for the analysis of controlled intersections. In *TRB 2012 annual meeting*, May 2012.

Ministry for the Environment (2009) The New Zealand land cover database. Accessed 11 April 2013. *www.mfe.govt.nz/issues/land/land-cover-dbase/*

Mitchell, J, P Blagdon and C Kennedy (2008) Improved locational accuracy of SCRIM data using GPS. In *Proceedings of the 2nd International Road Surface Friction Conference*, Cheltenham, UK, May 2008.

Mullenix, D, J Fulton, T Harbuck, and A Winstead (2009) *Update on GPS: new civilian accessible signals – L1C, L2C, and L5.* Precision Agriculture Series, Timely Information, Agriculture, Natural Resources and Forestry.

Munoz, D, F Bouchereau, C Vargas and R Enriquez-Caldera (2009) *Position location techniques and applications*. Burlington, MA: Academic Press. 296pp.

New Zealand Asset Management Support (2011) *International infrastructure management manual*. 2nd ed. Wellington: The NAMS Group.

New Zealand Transport Agency (2004) *Location referencing management system (LRMS) manual*. Accessed 7 May 2013. www.nzta.govt.nz/resources/location-ref-management-sys-manual/lrms.html

New Zealand Transport Agency (2009) *State highway database operations manual*. NZ Transport Agency manual number SM050. 108pp.

Nguyen, K and Z Luo (2013) Evaluation of Bluetooth properties for indoor localisation. Pp127–149 in *Progress in location-based services*. JM Krisp (Ed). Berlin Heidelberg: Springer-Verlag.

Nikander, J, J Järvi, M Usman and K Virrantaus (2013) Indoor and outdoor mobile navigation by using a combination of floor plans and street maps. Pp 233–249 in *Progress in location-based services*. J M Krisp (Ed). Berlin Heidelberg: Springer-Verlag.

Noury-Desvaux, B, P Abraham, G Mahé, T Sauvaget and G Leftheriotis (2011) The accuracy of a simple, low-cost GPS data logger/receiver to study outdoor human walking in view of health and clinical studies. *PLoS ONE 6*, no.9: e23027.

Parkins, A (2011) Increasing GNSS RTK availability with a new single-epoch batch partial ambiguity resolution algorithm. *GPS Solutions 15*, no.4: 391–402.

Patel, A, A Chasey and S Ariaratnam (2010) Integrating global positioning system with laser technology to capture as-built information during open-cut construction. *Journal of Pipeline Systems Engineering Practice 1*:147–155.

Peng, S and Y Morton (2013) A USRP2-based reconfigurable multi-constellation multi-frequency GNSS software receiver front end. *GPS Solutions 17*: *no.*1: 89–102.

Pérez-Ruiz, M, J Carballido, J Agüera and JA Gil (2011) Assessing GNSS correction signals for assisted guidance systems in agricultural vehicles. *Precision Agriculture 12*, no.5: 639–652.

Perrone E, N Mastin, R McKitrick and J Wu (2008) Using LRS change transactions generated externally to maintain data integrity in the pavement management system in North Carolina. In *Proceedings of the 7th International Conference on Managing Pavement Assets*, Calgary, Alberta, Canada, June 2008.

Porter, MM, MJ Whitton and DJ Kriellaars (2004) Assessing driving with the global positioning system: effect of differential correction. *Journal of the Transportation Research Board 1899*: 19–26.

Psimoulis, PA and SC Stiros (2008) Experimental assessment of the accuracy of GPS and RTS for the determination of the parameters of oscillation of major structures. *Computer-Aided Civil and Infrastructure Engineering 23*, no.5: 389–403.

Pullen, S, T Walter and P Enge (2011) SBAS and GBAS integrity for non-aviation users: moving away from 'specific risk'. In *Proceedings of the International Technical Meeting of The Institute of Navigation*, San Diego, CA, 24–26 January 24, pp533–545.

Quddus, MA and NR Velaga (2012) Enhancing vehicle positioning data through map-matching. Pp 343–364 in *Handbook of intelligent vehicles*. A Eskandarian (Ed). London: Springer-Verlag.

Realini E, D Yoshida, M Reguzzoni and V Raghavan (2012) Enhanced satellite positioning as a web service with goGPS open source software. *Applied Geomatics 4*, no.2:135–142

Rieser-Schüssler, N (2011) Capitalising modern data sources for observing and modelling transport behaviour. *Institute for Transport Planning and Systems Zurich working paper 707*. 30pp.

Rife, J (2011) Collaboration-enhanced receiver integrity monitoring with common residual estimation. In *Proceedings of the14th International IEEE Conference on Intelligent Transportation Systems (ITSC)*, October 2011, pp13–18.

Rizos, C, Y Li, N Politi, J Barnes and N Gambale (2011) Locata: A new constellation for high accuracy outdoor and indoor positioning. *FIG (International Federation of Surveyors) Working Week*, *paper 4917*. Marrakech, Morocco, May 2011.

Romanovas, M, V Goridko, L Klingbeil, M Bourouah, A Al-Jawad, M Traechtler and YM Huettinger (2013) Pedestrian indoor localization using foot mounted inertial sensors in combination with a magnetometer, a barometer and RFID. Pp151–172 in *Progress in location-based services*. J M Krisp (Ed). Berlin Heidelberg: Springer-Verlag.

Royal Institution of Chartered Surveyors (RICS) (2010) Guidelines for the use of GNSS in land surveying and mapping. *RICS guidance note, 2nd edition (GN 11/2010).* Coventry, UK.

Saeki, M and M Hori (2006) Development of an accurate positioning system using low-cost L1 GPS receivers. *Computer-Aided Civil and Infrastructure Engineering 21*: 258–267.

Sahinoglu, Z, S Gezici and I Guvenc (2008) *Ultra-wideband positioning systems: theoretical limits, ranging algorithms, and protocols*. Cambridge UK: Cambridge University Press. 268pp.

Samama, N (2008) *Global positioning: technologies and performance*. Hoboken NJ, USA: John Wiley & Sons. 420pp.

Serr, K, T Windholz, and K Weber (2006) Comparing GPS receivers: a field study. *URISA Journal 18*, no.2: 19–23.

Shin, E (2001) *Accuracy improvement of low cost INS/GPS for land application*, M.Sc. Thesis, Department of Geomatics Engineering, University of Calgary, Canada.

Takasu, T and A Yasuda (2009) Development of the low-cost RTK-GPS receiver with an open source program package RTKLIB. *International Symposium on GPS/GNSS*, Jeju, Korea.

Toledo-Moreo, R, M Zamora-Izquierdo, B Ubeda-Minarro and A Gandoacute (2007) High-integrity IMM-EKF-based road vehicle navigation with low-cost GPS/SBAS/INS. *IEEE Transactions on Intelligent Transportation Systems 8*, no.4: 491–511.

Toledo-Moreo, R, M Zamora-Izquierdo (2010) Collision avoidance support in roads with lateral and longitudinal manoeuvre prediction by fusing GPS/IMU and digital maps. *Transportation Research part C 18:* 611–625.

Trimble (2012) *Trimble floodlight technology*. Accessed 1 May 2013. http://trl.trimble.com/docushare/dsweb/Get/Document-528912/022501-264B_Floodlight%20Technology%20Brief_DS_0412_MGIS_LR.pdf

Trimble Navigation Limited (2013) Mapping and GIS product comparison: accurate GIS data collection where and when you need it. *Trimble Navigation Limited brochure*. 2pp.

Uren, J and WF Price (2010) *Surveying for engineers,* 5th ed. Palgrave MacMillan. 816pp.

Vaghefi, K, R Oats, D Harris, T Ahlborn, C Brooks, K Endsley, C Roussi, R Shuchman, J Burns and R Dobson (2012). Evaluation of commercially available remote sensors for highway bridge condition assessment. *Journal of Bridge Engineering 17*: 886–895.

van Digglen, F (2009) *A-GPS: assisted GPS, GNSS and SBAS.* Norwood, MA, USA: Artech House.

Vu, TT (2011) Building extraction from high-resolution satellite image for tsunami early damage estimation *Applied Geomatics 3*, no.2: 75–81.

Wang, W-C (2012) Developing a line-of-sight based algorithm for urban street network generalization. *Applied Geomatics 4*, no.2: 67–74.

Wideberg, J, P Luque and D Mantaras (2012) A smartphone application to extract safety and environmental related information from the OBD–II interface of a car. *International Journal of Vehicle Systems Modelling and Testing 7*, no.1: 1–11.

Wilson, C (2012) Probes and intelligent vehicles. Pp1145–1172 in *Handbook of intelligent vehicles*. A Eskandarian (Ed). London: Springer-Verlag.

Wing, MG, A Eklund and LD Kellogg (2005) Consumer-grade global positioning system (GPS) accuracy and reliability. *Journal of Forestry 103*, no.4: 169–173.

Wong, G, RE Phelts, T Walter and P Enge (2011) Alternative characterization of analog signal deformation for GNSS-GPS satellites. In *Proceedings of the 2011 International Technical Meeting of The Institute of Navigation*, San Diego, CA, January 2011, pp497–507.

Yoshida, D, X Song and V Raghavan (2010) Development of track log and point of interest management system using free and open source software. *Applied Geomatics 2*, no.3: 123–135.

Yue, Y, Ag Yeh and Q Li (2008) Road network model for vehicle navigation using traffic direction approach. Pp613–629 in *Headway in Spatial Data Handling, Proceedings of the 13th International Symposium on Spatial Data Handling.* A Ruas and C Gold (Eds).

Yun, Y, J Cho and M-B Heo (2012) Automated determination of fault detection thresholds for integrity monitoring algorithms of GNSS augmentation systems. In *Proceedings of IEEE/ION PLANS 2012*, Myrtle Beach, South Carolina, April 2012, pp1141–1149.

Zandbergen, PA (2009) Accuracy of iPhone locations: a Comparison of assisted GPS, WiFi and cellular positioning. *Transactions in GIS 13*, no.1: 5–25.

Zhang, C and A Elaksher (2012) An unmanned aerial vehicle-based imaging system for 3D measurement of unpaved road surface distresses. *Computer-Aided Civil and Infrastructure Engineering 27*, no.2: 118–129.

Zhang, K, G Liu, F Wu, F and L Densley (2009) An investigation of the signal performance of the current and future GNSS in typical urban canyons in Australia using a high fidelity 3D urban model. Pp407–420 in *Location based services and teleCartography II: from sensor fusion to context models*. G Gartner and K Rehrl (Eds). London: Springer.

Zhou, Y, M Chowdhury, J Martin, K Wang, X Kang and JM Westall (2009) Field performance study of a regional WiMAX network for intelligent transportation system applications. *Journal of the Transportation Research Board 2129*: 121–128.

Zhu, Z and I Brilakis (2009) Comparison of optical sensor-based spatial data collection techniques for civil infrastructure modeling. *Journal of Computing in Civil Engineering 23*, no.3: 170–177.

Zipf, A and MM Jöst (2012) Location-based services. Pp 417–421 in *Springer handbook of geographic information*. W Kresse and DM Danko (Eds). Berlin Heidelberg: Springer-Verlag.

Appendix A: Industry information request

The following email was sent to industry representatives:

Greetings

We are currently undertaking research for the New Zealand Transport Agency (NZTA) on accurate and affordable methods of location technology on the NZTA highway network, suitable for use by contractors and consultants – in fact any of NZTA's agents, and possibly applicable to other agencies with an interest in the highway network. The key use for this technology will be to locate and update road asset data, and could be a mobile or desktop based technology.

Part of this research involves engaging with industry representatives within New Zealand so we would be very interested in *any information that you could provide that the NZTA should be aware of. Information on the use or development of this sort of technology in the transport and related sectors by your organisation or others* would be excellent.

If you would like to contribute some information and/or a summary list of products you feel might have serious application in this field and any references by about the 8th of February, that would be most appreciated.

We intend to measure each technology against a series of key performance indicators. These KPIs include:

a) Accuracy - looking at accuracies better than 1m through to about 5m.

b) Geographic Coverage of the NZTA State Highway network. The ability for this technology to be used across the network.

c) Ease of use, especially by roading contractors.

d) Compatibility with existing asset systems particularly those used by the NZTA (e.g. RAMM).

e) Indication of Cost (set up costs, field units and any necessary office software).

f) Track record in asset management situations both within NZ and overseas.

g) The future outlook for this technology. Will it be supported in the future and is it in line with other technology trends.

Please feel free to forward this email onto another more appropriate person in your organisation.

Regards

Appendix B: Interview schedule

Organisation name:
Interviewee name:
Date of interview:

1 How do you currently use Location Technology to locate people, assets or events? This can be both mobile technology or field based tools

What hardware and software do you use?

Why do you use it primarily (assets, people, and events?)

2 Can you see potential for more use of this sort of technology within your organisation?

Is it more a wider use of current technology or the implementation of new technology?

If new technology what sort of tools do you think could meet some of your requirements (higher accuracy GPS, mobile devices, desktop or web based software)

3 Barriers

Are there any barriers stopping your organisation from using location technology more? (cost, management, lack of knowledge/staff, coordination)

4 Learnings

From previous implementations of location technology (or any similar mobile technology) what things helped this succeed or fail within your organisation?

List Success factors (e.g. training, appropriately resourced, software easy to use)

List Failure factors (e.g. no training, software not usable, lack of consistency across organisation)

Appendix C: Glossary

AMA	Auckland Motorway Alliance
C/A	coarse/acquisition (code)
CAD	computer-aided design
C-ITS	cooperative intelligent transport systems
CORS	continually operating reference station
CRCSI	Cooperative Research Centre for Spatial Information
DOTD	Department of Transportation and Development (Louisiana)
GBAS	ground-based augmentation system(s)
GIS	geographic information system(s)
GLONASS	Russian global navigation satellite system
GNSS	global navigation satellite system(s)
GPS	global positioning system(s)
HSD	high-speed data
IMU	inertial measurement units
INS	inertial navigation system
ITS	intelligent transport system
KMP	kilometre marker posts
KPI	key performance indicator
LINZ	Land Information New Zealand
MAC	media access control
MMS	mobile mapping system
MSAS	multi-functional satellite augmentation system
NCDOT	North Carolina Department of Transportation
NCRST	National Consortium on Remote Sensing in Transportation (USA)
NZGD	New Zealand Geodetic Datum
NZFS	New Zealand Fire Service
NZTM	New Zealand Transverse Mercator
P	precision (code)
PDA	personal digital assistant
PDOP	position dilution of precision
Police	New Zealand Police
QA	quality assurance
QR	quick read
RAM	road asset management
RAMM	Road Asset Maintenance Management (a software application)

RFID	radio frequency identification
RP	route position
RS	reference stations
RSL	RAMM Software Limited
RTK	real-time kinetic
SBAS	satellite-based augmentation system
SCRIM	sideway-force coefficient routine investigation machine
SHDOM	*State highway database operations manual* (NZ Transport Agency 2004)
Transport Agency	New Zealand Transport Agency
WAAS	wide-area augmentation system