An investigation into the deployment of an advisory ISA system in New Zealand

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MWH New Zealand Ltd was contracted by NZTA in 2010 to carry out this research.

Keywords: adaptation, advisory, intelligent, investigation, ISA, New Zealand, NZ Transport Agency, research, speed, system, trial

An important note for the reader

Erratum

29 October 2013

Acknowledgements, page 4 – the Ministry of Transport Steering Group representative, Mark Frampton was incorrectly listed as ‘Mike’ Frampton. The acknowledgement has been corrected.

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Abbreviations and acronyms

AA	Automobile Association of New Zealand
ANOVA	analysis of variance
ABS	anti-lock braking system
DSRC	dedicated short-range communications
ECU	electronic control unit
ESR	The Institute of Environmental Science and Research Limited
ETSC	European Transport Safety Council
GIS	geographical information system
GNSS	global navigation satellite systems
GPRS	general packet radio service
GPS	global positioning system
HMI	human–machine interface
ISA	Intelligent Speed Adaptation
ITS	Intelligent Transport Systems
MED	Ministry of Economic Development
MoT	Ministry of Transport
NZTA	NZ Transport Agency
PSL	posted speed limit
RCA	road controlling authority
SD	secure digital
SH	state highway
TAC	Transport Accident Commission
UNECE	United Nations Economic Commission for Europe

Contents

Executive summary

Intelligent Speed Adaptation (ISA) is a type of in-vehicle technology system that assists drivers to keep to or below the speed limit, by using GPS and speed limit 'maps' so the ISA system knows the location of the vehicle and the current speed limit. The ISA system warns drivers via visual and audio feedback when they exceed the speed limit. The typical ISA categories are 'advisory', where the speed limit is displayed and the driver is reminded of changes in the speed limit; 'voluntary', which allows the driver to enable and disable the vehicle's control of the maximum speed; and 'mandatory', where the vehicle's maximum speed is limited at all times. Further, three categories define the currency of the speed limit information. These are 'fixed', where the vehicle is informed of the posted speed limit; 'variable', where the vehicle is informed of additional locations (such as sharp bends) where a lower speed limit or speed advice is recommended or implemented; and 'dynamic', where speed limit information may vary both temporarily and spatially. This research covered only advisory ISA, and looked at both 'fixed' and 'variable' advisory ISA systems.

The research evaluated the likely success of the introduction of advisory ISA technology to New Zealand and covered: a literature review of real-world trials; potential uptake incentives; setting of speed limits and the development of a speed limit 'map'; the coverage and accuracy of Global Navigation Satellite Systems (GNSS) in New Zealand; focus group and experimental trial results; benefit–cost analysis; and a summary of institutional and other barriers. The research was undertaken from April 2011 to December 2012.

Encouraging uptake: The aspects studied related to encouraging drivers to either purchase a vehicle with a speed-limiting device or to retrofit their vehicle with this function, as well as drivers' willingness, for an advisory ISA, to turn the function on and comply with the information.

Setting of speed limits: All the current ISA systems start with the need and ability to inform drivers about the existing fixed speed limits. Previous research has favoured GPS/navigation-based systems. Thus a key component of the deployment of ISA in New Zealand would be the development of a comprehensive and accurate national electronic speed limit management system.

Coverage, reliability and accuracy of Global Navigation Satellite System (GNSS) receivers in New Zealand: An initial analysis of GPS coverage over the state highway network indicated that more than 95% coverage could be expected; however, an ISA system would likely be unreliable, or even unusable, in about 12 locations (over Route Stations of around 10km in length), with the potential to drop out for shorter lengths (up to 500m) over much of the country – this appears to vary from year to year.

User acceptability of advisory ISA focus groups: Four focus groups from different driving populations (young drivers, older drivers, fleet drivers and the general population) discussed the acceptability of advisory ISA technology to potential users. The key findings were as follows:

- The overall feedback across three of the groups (older, young and fleet driver groups) was positive, in line with international findings, suggesting that with the right incentives and with good design, these driving populations would have good uptake of advisory ISA technology. However, the general sample of private vehicle drivers between 25 and 64 years of age were generally dismissive about the devices.
- Older driver and fleet driver groups stated that they would most likely comply with the warnings of the ISA device if they had one. In line with previous studies, the young driver group suggested they would be unlikely to comply at all times.
- No group was seen as an ideal target group for ISA, but most thought the community could benefit.

- This study was unique in gathering user feedback on the ideal specific elements people would like in a device.
- Participants initially struggled to understand the difference between ISA and other current GPS devices. Even when they understood the difference, the need for two separate devices was questioned, with suggestions preferring one device to fulfil both standard GPS and ISA functions.

Advisory ISA participant field trials: Field trials were undertaken to assess user speed compliance with advisory ISA, the impact of ISA on speed selection, and attitudes to ISA in both a fixed ISA (speed limit information only) and variable ISA (speed limit and curve advisory information) condition.

Journey time: The ISA conditions made journey times more consistent and uniform between participants.

Driver speed compliance: Both ISA conditions significantly reduced driver speeds, compared with the 'baseline' condition across a range of road types, although the effects were relatively small.

User perception and design preferences: The overwhelming feedback from participants was the need to customise the ISA technology to suit individual preferences, particularly regarding: the volume of the device (both up and down); the threshold at which feedback is received; the amount of warning received before a speed change or advisory; the choice of auditory or visual feedback for different information; and the use of speech warnings rather than sound warnings. Other suggested features were: warnings for going too far under the speed limit (ie driving too slowly); having the actual speed the vehicle is travelling displayed; and the addition of other information including school zones, railway crossings, and live updated information such as temporary speed zones.

Fixed ISA versus Variable ISA: The fixed ISA condition was found to have a positive influence on participant behaviour and was also rated positively by drivers. The results for the variable ISA condition indicated this condition improved driver behaviour, particularly around hazard advisory zones. However, there was stronger resistance to using this type of ISA, some of which could be addressed by allowing more customisation of the device (eg audio feedback sounds).

Implications of the study findings: Overall, advisory ISA systems consistently improved speed compliance, and therefore safety, even after a relatively short exposure (one day). The increase in speed compliance of about 7% was more positive than previous overseas advisory ISA findings, suggesting that New Zealand drivers would respond well to the implementation of advisory ISA. In rural conditions with winding curves, the variable ISA condition significantly improved compliance with advisory curve speed signs. Thus variable ISA offers a proactive and potentially cost-effective solution to a key accident risk in New Zealand.

ISA benefit–cost analysis: The predicted crash reductions ranged from 1% to 22% for the different crash severities, road types and ISA conditions considered. These equated to annual benefits of $269 million for fixed ISA. For variable ISA the annual benefits were between $173 and $292 million, or if it was applied to all curves with radii of 400m or less, the benefits would range from $300 to $396 million. The fixed costs of deploying an advisory ISA system in New Zealand would be exceptionally low, compared with the benefits. The benefit–cost ratio (BCR) was very sensitive to changes in user costs. The costs to users of purchasing ISA devices and updating their map data would be voluntary costs, with users able to choose whether to spend their money on ISA, and also the option that would suit them best (eg live data transfer or free map download). Most users may choose to use ISA to reduce the chance of getting speeding fines and to reduce the burden of the driving task. In this case, it could be argued that user costs should not be considered to be borne by ISA. This would have a major impact on the BCR, taking it from 0.6 to 2.9 for the 100% uptake scenarios considered, to requiring only 0.5% uptake to achieve BCRs of 9–21 under the scenarios considered.

Advisory ISA – institutional barriers: Advisory ISA would be likely to encounter few potential institutional, regulatory or other barriers outside those addressed elsewhere in this project. The main issues would be around practical implementation relating to: the speed information relayed to the driver differing from the speeds measured by enforcement devices, leading to complications for enforcement; concern by motor industry groups re opportunities for timely input into any future government proposals for changes to requirements regarding the fitting of technology to vehicles; concern over confidentiality of information; concerns about 'big brother/government control ('nanny state').

However, there are a large number of technical issues related to mapping, speed measurement, speed limit databases, radio frequencies and confidentiality that may involve expensive policy work and legislative change. In terms of government expenditure constraints, this may act as a barrier to the policy and legislative work required and also to finding timely legislative 'slots'. There are also unknowns regarding the number of existing ISA devices that would comply with any proposed legislative changes, or any willingness by vehicle manufacturers to comply with these proposed legislative changes. The need for considerable promotion may be required, as the 25–64 age group appears to have some resistance to ISA, according to focus groups associated with this project – these costs may also be a barrier.

The following recommendations are based on the experimental trial findings:

- Very little research has been done regarding the Human–Machine Interface, despite it being critical for successful uptake. A trial with a range of customised options (eg volume, tone, visual display or speed thresholds) should be undertaken to examine user acceptance.
- In the variable ISA condition, the speed thresholds and also the location before the curve at which feedback begins will strongly influence usability. The relationship between willingness to accept lower speed thresholds versus the level of incentive could be assessed. Users may be more tolerant of ISA if they are provided with incremental benefits for self-selecting lower speed thresholds. Determining effective ways to increase device usability will be required for successful implementation in New Zealand, particularly for variable ISA.
- The experimental trials in this study were of a comparatively small sample size and duration. A more extensive study would provide further information, particularly around long-term effectiveness, including any compensation or over-reliance on the system and the level of use of the device, which would inform the decision on whether to deploy an advisory ISA system in New Zealand.

The following recommendations are based on the benefit–cost study:

- Further investigation regarding the deployment of an advisory ISA system in New Zealand should be undertaken, as the system could lead to significant benefits at potentially little set-up and operational cost. The deployment of advisory ISA would still be economically viable even with very low levels (<1%) of uptake.
- Further work regarding the preferred deployment scenario, and to fully scope the development of an ISA system and all of the associated costs, should be undertaken.
- Further study to fully understand the potential additional benefits of an ISA system that includes advisory curve warnings as well as speed limit information, and to understand and eliminate any adverse effects (such as compensatory behaviour) should be undertaken. This should include consideration of: only signed advisory curves, curves that are less than a certain radius, or all curves; and work with focus groups to understand the user acceptance implications of having ISA curve advisory speeds that may differ from the signed curve advisory speed.

- A study to address the apparent inconsistency in advisory curve signage that occurs over the national road network should be undertaken, by adapting existing predictive models or developing new models to allow theoretical calculation of advisory speeds for signs, rather than relying on ball-bank gauge measurements, which can be susceptible to human error.

Abstract

Excessive and inappropriate speed on our roads is a significant issue in New Zealand, and loss-of-control crashes, on rural curves in particular, are a key crash contributor. This research investigated the deployment of an advisory Intelligent Speed Adaptation (ISA) system in New Zealand.

The predicted crash-reduction benefits of two ISA variants were determined following real-world trials of a 'fixed' ISA system that provided drivers with speed limit information and warned them when they were exceeding the speed limit, and a 'variable' ISA system that provided drivers with feedback on their speeds while negotiating curves and other road features that were signposted with advisory speeds. These crash-reduction benefits were compared with estimated implementation and operating costs to determine the economic viability of deploying an advisory system in New Zealand.

The research also examined a range of potential barriers. Focus groups were used to identify user acceptance issues, and local and central government and the motor industry were consulted to identify potential institutional, regulatory or other barriers.

This research also looked at how speed limit and advisory curve information may be transferred to a vehicle. An assessment of GPS reliability and coverage in New Zealand was made, as well as the development of a framework on which to build an e-speed limit management system.

1 Introduction

Intelligent Speed Adaptation (ISA) is a type of in-vehicle technology system that assists drivers to keep to or below the speed limit, most commonly by using GPS and speed limit 'maps' so the ISA system knows where the vehicle is and what the speed limit of the road is. The ISA system warns drivers via visual and audio feedback when they exceed the speed limit. Some ISA systems also restrict the vehicle's speed, not allowing the vehicle to exceed the speed limit; a form of intelligent governor for which the maximum governed speed is the speed limit of the road being travelled. ISA is an innovative, emerging technology that could significantly reduce the number of deaths and injuries on our roads. It is a technological solution primarily aimed at improving driver speed behaviour and reducing trauma should crashes occur. Previous international research has shown that ISA has significant safety benefits.

ISA has been the subject of research initiatives since the first Swedish studies in the early 1990s (Persson et al 1993). In the late 1990s to mid-2000s,a large number of studies were initiated throughout Europe, including projects in the UK (Carsten and Tate 2000), Denmark (Lahrman et al 2001), the Netherlands (Duynstee et al 2001), and France (Ehrlich et al 2006), as well as EU studies under the PROSPER project with experiments in Hungary and Spain (Varhelyi et al 2005). Following on from these, initial trials have been larger-scale projects such as the 'ISA-UK (2001–2006)'.

More recently, interest has been growing in Australia, initially with the 'TAC SafeCar' project, and more recently with trials in Wollongong (NSW[1] Centre for Road Safety 2010b), Adelaide and Perth.

With the research now matured, and with the combination of technological advancements and declining costs for electronic goods, this is a pertinent time to investigate the deployment of an ISA system in New Zealand.

1.1 Definitions of ISA variants or typologies

While all studies of these systems are broadly termed ISA studies, the number of variations researched is almost greater than the number of studies, as some studies consider multiple variations.

Carsten and Tate (1997) defined ISA typologies in terms of the level of interaction with the driver and the types of speed limit information displayed. They later refined this concept as a matrix (Carsten and Tate 2005). A further axis of the ISA system matrix is characterised by how *intervening* the ISA system is.

The typical categories are as follows:

- Advisory: The speed limit is displayed, reminding the driver of changes in the speed limit.
- Voluntary ('driver select'): The driver can enable and disable control by the vehicle of the maximum speed.
- Mandatory ('intelligent governor'): The maximum speed of the vehicle is limited at all times.

These three ISA variants have been shown to have significantly different safety benefits. However, a second dimension can be added, looking at the *currency* of the speed limit information. Again, three categories are defined here:

- Fixed: The vehicle is informed of the posted speed limit.

[1] New South Wales.

- Variable: The vehicle is additionally informed of certain locations where a lower speed limit or advice is recommended or implemented – eg around pedestrian crossings or on the approach to a sharp bend. In this case the speed limits (or advice) may vary spatially.
- Dynamic: In addition to the 'fixed' and 'variable' functionality, speed limits may vary both temporarily and spatially – ie lower speeds may be implemented due to weather conditions, in response to incidents or congestion, or around schools when students are arriving or leaving.

This research project covered only advisory ISA, and looked at both 'fixed' and 'variable' advisory ISA systems.

ISA is one technology in the family of Intelligent Transport Systems (ITS), which use advanced information, electronic, communications and other technologies for the management and operation of transport networks.

2 Background

Excessive and inappropriate vehicle speed on the road is a significant issue in New Zealand. In the 2011 calendar year, for instance, 30% of all fatal crashes and 20% of all serious-injury crashes had speeding as a contributing factor. In 2011, 77 people died in New Zealand as a result of being involved in a crash in which inappropriate speed was identified as a causal factor, with 67% of these crashes occurring on the open road. A further 351 people were seriously injured as a result of being in a speeding-related crash, with 61% of these crashes occurring on the open road. The predominant crash problem in New Zealand relates to rural roads rather than urban roads, and in particular, loss of control on rural roads. Almost half (46%) of injury crashes involved a loss-of-control or head-on collision on bends. It is for this reason that this research project investigated both 'fixed' and 'variable' advisory ISA typologies.

Ministry of Transport (MoT) research on open road speeds in New Zealand shows that since 2006, the percentage of drivers travelling at more than the open road speed limit of 100km/h has fluctuated between 29% and 31%, with the 85th percentile open road speed stable at 103km/h. For urban roads, the research reveals that for 2011, 59% of drivers exceeded the 50km/h posted speed limit, with an 85th percentile urban road speed of 57km/h. The benefits of reduced speeds are well established (covered in chapter 8 of this report), and clearly there is an urgent need to improve speed limit compliance in the New Zealand driving population.

This research was also driven by the New Zealand Road Safety Strategy 2010–2020, *Safer journeys* (MoT 2010), which has 'safer speeds' as one of the primary tenets of the safe-system approach that underpins the strategy for road safety through to 2020 and beyond.

2.1 Objective

The primary objective of this research was to investigate the issues associated with the deployment of advisory ISA in a New Zealand context.

This research evaluated the likely success of the introduction of advisory ISA technology to New Zealand through six distinct components, or work packages, examining a range of potential barriers. Common barriers cited in the literature (chapters 3 and 4) to the introduction of ISA technologies include technical demands, user perceptions and acceptance, political and institutional barriers, and costs.

The technical barriers and feasibility of developing a suitable speed limit map were also examined (chapter 5), as well as the technical requirements of transferring this information to vehicles (chapter 6).

The perceptions and acceptance of ISA in the general public and professional driving population was examined through focus groups and an on-road trial involving willing participants (chapters 7 and 8), and the level of compliance that could be expected from the introduction of ISA was evaluated (chapter 8).

A benefit–cost analysis was undertaken (chapter 9) and an assessment was made of the institutional and political barriers that could restrict the uptake of ISA technology in New Zealand (chapter 10).

3 Review of real-world trials

3.1 Scope

This chapter reviews the methodology and results of the real-world trials that have been carried out to evaluate the impact of Intelligent Speed Adaptation (ISA) on driver behaviour. This report does not contain references to projects carried out before 2005; a review of these can be found in Jamson et al (2006), and a large proportion of that research has been reported in a special issue on ISA in *Accident Analysis & Prevention 48* (2012). Since then, the rate at which pure ISA research projects have been carried out has slowed; there is a realisation that it is not the functionality of ISA or its potential for accident savings that require investigation, as these issues have been comprehensively proven by previous studies (eg Jamson et al 2006), but rather the way in which it is implemented from both the drivers' and policy makers' viewpoints. From a deployment perspective, there has been substantially more focus on acceptance and incentives, with particular focus on advisory and low-cost ISA systems.

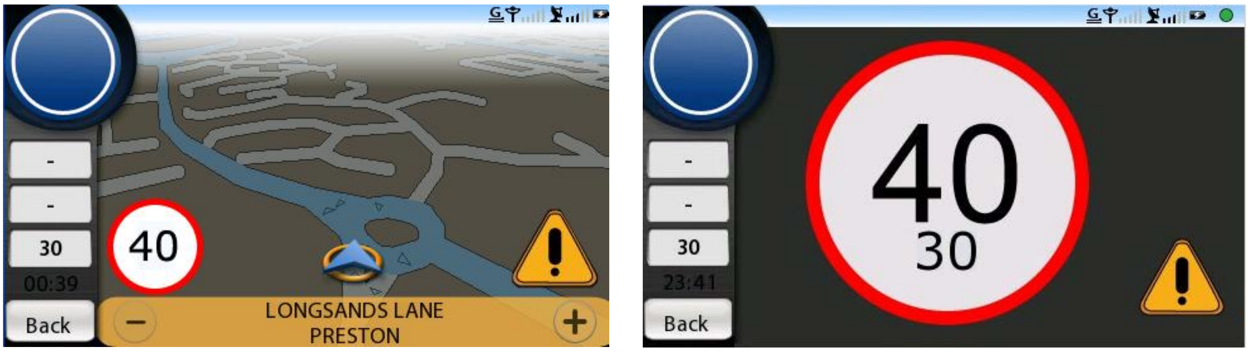
The real-world trials that are discussed below include:

- Lancashire ISA project (University of Leeds, UK)
- LAVIA (INRETS, France)
- NSW Centre for Road Safety (Australia)
- Pay As You Speed (Denmark)
- Intelligent Speed Adaptation in Company Vehicles (Denmark)
- Ghent ISA Trial (Belgium)
- London ISA (Transport for London, UK)
- Effects of an Advisory Warning and a Cash Bonus on Speeding Behaviour (National Highway Traffic Safety Administration and Old Dominion)
- Speed Choice and Modelling the Impacts of Speed on Safety and the Environment (Transport Canada)
- SafeMiles project (Transport Canada)
- Development of a Kilometer-Based Rewards System to Encourage Safer Driving Practices (University of Sydney).

3.2 Lancashire ISA project (University of Leeds, UK)

The Lancashire ISA project trialled an advisory ISA system in 2005 (Lai et al 2012b). The hardware consisted of a portable satellite navigation system with an add-on of speed limit information. There were two modes of visual display of the speed limit information, as shown in figure 3.1. The display mode was user selectable.

Figure 3.1 Visual display of the ISA system



The ISA system conveyed information to the user via visual and auditory modes (see table 3.1 below). The system compared vehicle speed (obtained via GPS) against the on-board speed limit database. As soon as speeding was detected, the warning was given (ie there was no tolerance threshold). The auditory warning would repeat continuously, every second, until the vehicle speed was below the speed limit.

Table 3.1 HMI of the ISA system

Event	Auditory display	Visual display
3 seconds before change of speed limit	Double drums	40
Vehicle speed >SL	One beep	40
Vehicle speed ≥SL + 5mph	Triple beeps	40

Vehicle speeds were recorded at 1Hz[2] and periodically transmitted back to the data centre. The trial lasted nine months for each participant, although the entire trial involved a staggered start and finish across the fleet for project management purposes. ISA functionality was disabled for the first two months, serving as baseline (phase 1). At the end of the baseline period, ISA functionality was switched on remotely and stayed on for the remaining seven months (phase 2). This trial collected over 2.8 million miles (4.5 million kilometres) of driving data, contributed by 402 drivers, using a within-subjects[3] design.

Since the advisory ISA was delivered by means of a nomadic device, whether or not a driver's choice of speed was influenced by ISA was dependent on whether the driver chose to connect the screen before commencing a trip. The effectiveness of advisory ISA has therefore been examined by defining this data in two different ways:

- ISA available: This refers to the data collected throughout phase 2 of the trial, denoting that ISA was used intermittently over a period of time.
- ISA in use: This refers to the data recorded in phase 2 when the screen was connected, denoting that the drivers had chosen to receive the speed limit information.

[2] The 1Hz refreshment rate was a limitation of the system design, which consisted of a nomadic satellite navigation system and a communication module (supplied by Mobile Devices Ltd), with an extra layer of speed limit information and warning functionality (developed by Smart Car Technologies Pty Ltd).

[3] A within-subjects design is an experiment in which the same group of subjects serves in more than one treatment.

The results suggested that advisory ISA can be effective in curtailing speeding, as shown in figures 3.2 and 3.3. It is especially impressive that the effect of advisory ISA is prominent on 70mph (113km/h) roads, even when only used intermittently.

Figure 3.2 Speed distribution on 30mph roads

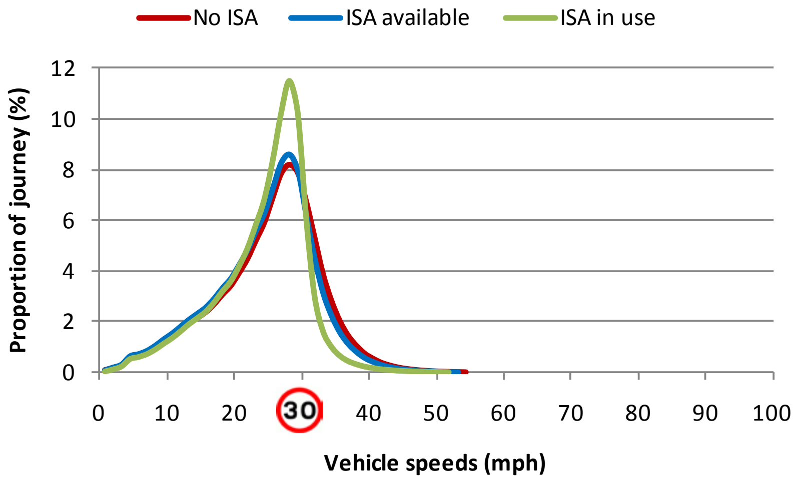


Figure 3.3 Speed distribution on 30mph roads

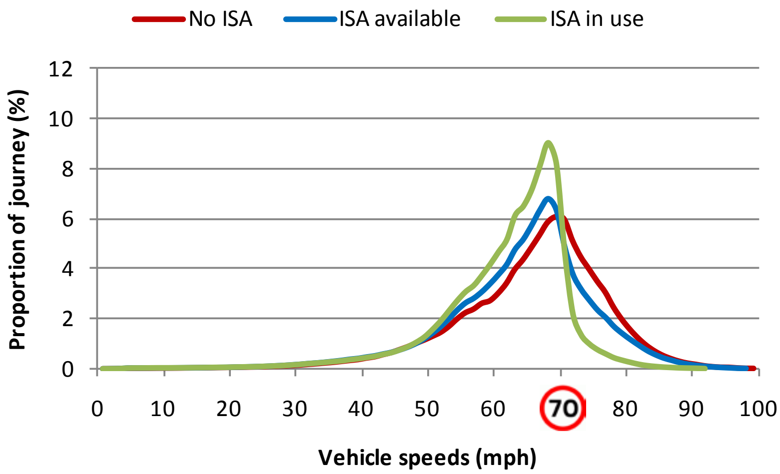


Table 3.2 shows the speed reductions and the proportion of distance travelled over the speed limit when ISA was in use, across different speed limit zones. Numbers in bold and underlined denote statistical significance at 0.05, while numbers that are shaded, in bold and underlined denote significance at the 0.01 level.

The reduction in speeds was effective across the majority of speed limit zones, but was not of great magnitude; the most reduced was the 85th percentile speeds on 70mph roads. However, the reduction in the proportion of speeding demonstrated a fairly large effect:

- on 30mph roads, there was a 30% reduction
- on 70mph roads there was a 56% reduction.

This is not surprising, given that ISA targets the high end of the speed distribution and changes the shape of the speed distribution, rather than just shifting the distribution towards the lower end. The effectiveness of advisory ISA was reduced when the usage decreased (see table 3.2). However, even when ISA was only used intermittently over time, its effect in reducing speeding was still prominent, as shown in table 3.3, with 18% and 31% reduction in speeding on 30mph and 70mph roads respectively.

Table 3.2 Reduction in speeds and speeding from 'No ISA' to 'ISA in use'

	Speed limit zone					
	20	**30**	**40**	**50**	**60**	**70**
Mean	-1%	**-2%**	**-3%**	**-2%**	-1%	**-4%**
85th	-3%	**-5%**	**-4%**	**-3%**	**-2%**	**-6%**
%_speeding	-7%	**-30%**	**-40%**	**-44%**	**-21%**	**-56%**

Table 3.3 Reduction in speeds and speeding from 'No ISA' to 'ISA available'

	Speed limit zone					
	20	**30**	**40**	**50**	**60**	**70**
Mean	-1%	**-3%**	**-2%**	**-2%**	**-1%**	**-2%**
85th	0%	**-2%**	**-2%**	**-1%**	**-1%**	**-2%**
%_speeding	**-6%**	**-18%**	**-23%**	**-24%**	**-16%**	**-31%**

The evidence also suggested that some demographic driver factors could influence the effect of advisory ISA. Advisory ISA was found to be less effective overall with drivers over 60 years old, mainly because the baseline speeds for this age group were lower than for other age groups. However, advisory ISA was effective at reducing the speeding of individuals within the older age group, whereas drivers aged 25 and below were more resistant to keeping their speed below the speed limit.

With respect to driving experience, defined as the number of years since passing the test, we found that in the novice group, advisory ISA was effective in reducing their higher speeds (ie the 85th percentile speeds), but these drivers were more resistant, overall, to keeping their speed below the speed limit. Higher-mileage drivers were also more resistant to keeping their speed below the speed limit, except for on 30mph roads. Gender did not appear to influence the pattern of the effectiveness of advisory ISA across speed limit zones.

To sum up, the analysis results suggested that advisory ISA could be effective in curtailing speeding, as long as the driver was willing to receive and act on the information.

3.3 LAVIA (INRETS, France)

The LAVIA project was initiated and financed in part by two divisions within the French Transport Ministry: the Road Traffic and Safety Division (DSCR), and the Research and Scientific Affairs Division (DRAST). Eight partners collaborated in this project: the French car manufacturers Renault and PSA Peugeot Citroën, the Laboratory for Accidentology, Biomechanics and the Study of Human Behaviour (LAB), the Southwest and

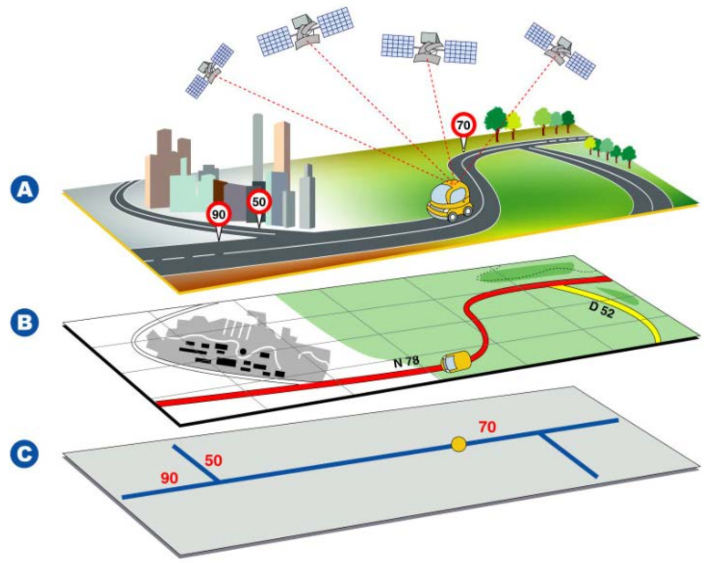
Mediterranean Regional Public Works Research Centres (CETE), the Paris Regional Public Works Division (DREIF), and the INRETS[4] and LCPC research organisations.

The LAVIA trial was carried out between 2001 and 2006 and evaluated three variants of the system:

- Advisory: Speed limits were indicated on the vehicle dashboard and an indicator light started to blink if the driver exceeded this limit.
- Voluntary active: The accelerator pedal could not be depressed further once the speed limit was reached. The driver could activate and deactivate the system when desired.
- Mandatory active: Identical to the previous mode except there was no ability to manually override the system.

In both of the active modes the driver could temporarily 'kickdown' (floor the accelerator), with the system reactivating once the vehicle returned to below the speed limit. Around 100 volunteer drivers were recruited from the Yvelines department or administrative division (approximately 1000km of highways and streets), west of Paris.

Figure 3.4 Diagram showing the LAVIA architecture (Pianelli et al 2007)



The absolute vehicle coordinates (A in figure 3.4) were calculated via GPS, the odometer and a gyro meter; the navigation system associated with a digital map associated these coordinates to a given road segment (B); and a database matched the speed limit with each road segment (C).

Firstly, 1000 drivers living within the experimental zone were interviewed. The aim was to investigate drivers' attitudes with respect to speed and ISA systems. Five hundred of these drivers were then asked to participate in the experimental stage, of which 192 replied positively. Ninety drivers were subsequently recruited to take part, with 44 using a Renault Laguna and the other 46 using a Peugeot 307. No control group was used.

In addition to the experimental work, extensive work was undertaken regarding acceptance of LAVIA. *A priori* acceptability of LAVIA was investigated by surveying 394 drivers who had never used the system. Of

[4] Now called IFSTTAR.

those 394 drivers, the acceptance level of the 90 drivers mentioned above was monitored by interviewing them after they had driven with each of the three variants of the system.

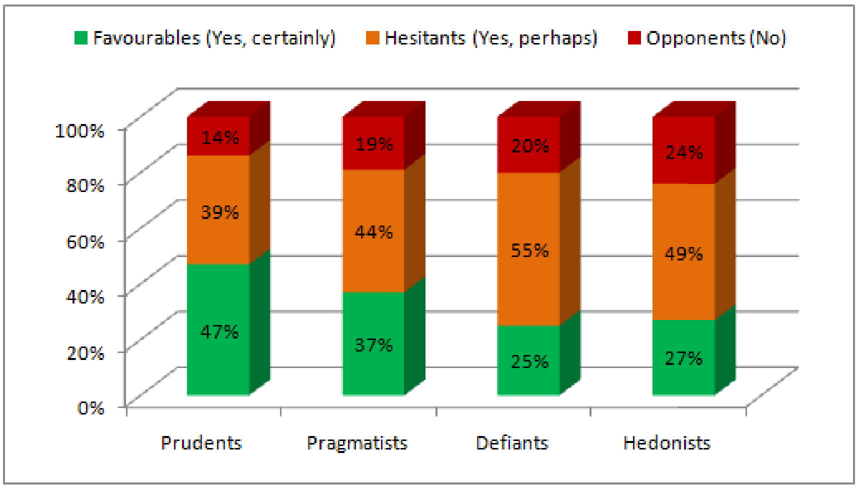
These two studies were carried out using the theoretical framework of social representations, which postulates that individuals appropriate reality and make a representation of it. It is this representation that becomes reality for each individual. For example, the 'fair trade phenomenon' challenges the injustices of conventional trade, which traditionally discriminates against the poorest, weakest producers. Fairtrade pushes for better prices, good working conditions, local sustainability, and fair terms of trade for farmers and workers in the developing world. It is a social innovation that is becoming more and more recognised worldwide, with trade organisations acting as entrepreneurs to influence policymakers. Sitting between these 'alternative' trade organisations and the policymakers are citizens (consumers), and it is thus important to gain understanding of the representations they have about such a phenomenon, given the well-established link between attitudes and behaviour. The idea behind social representations is that they are collectively produced and engendered; they thus represent something different from individual acceptance.

With regards to the social representations regarding speed, two main elements were found (pleasure and danger) and this enabled the following four groups of drivers to be identified:

- 'Prudent' drivers (55%): Their representation of speed is centred on danger; pleasure is not present in their representation.
- 'Pragmatists' (20%): Speed is neither a pleasure nor a danger; their representation is centred on the functional aspects of speed (gaining time, etc), enforcement and the vigilance required.
- 'Defiant' drivers (14%): Their representation of speed is based on the coexistence of the elements danger and pleasure.
- 'Hedonists' (10%): Their representation of speed is centred on its positive aspects: pleasure, rapidity and gaining time. Danger is not present in their representation.

With regards to the social representations of the LAVIA system, the Prudent group had a central core made up of elements that reflected the safe, functional aspects of LAVIA. For these drivers, LAVIA represented safety, peace of mind, compliance with speed limits, vigilance and aid. This representation of LAVIA was very positive. The Defiant group had a central core composed of the same functional elements: safety, peace of mind and compliance with speed limits. However, the element of constraint also appeared in the central core of their representation. Similarly, the Hedonists had this element of constraint in their central core. For them there was only one functional element: compliance with speed limits. The Pragmatists had a central core composed of functional elements: peace of mind, compliance with speed limits, comfort and vigilance. There was also the negative element of constraint. Thus, the representations of LAVIA depended directly on the social representations of speed (Pianelli et al 2007) (see figure 3.5).

Figure 3.5 ***A priori*** **acceptability of LAVIA for each group of drivers (Pianelli et al 2007)**



In the surveys that were carried out following exposure to ISA during the LAVIA trial, 87 of the 90 participants provided comprehensive data. The advisory ISA was the variant most accepted by drivers: 70% of drivers who had tried advisory LAVIA would 'certainly' accept it in their own vehicle and only 6% would not accept it. The voluntary mode was less accepted, with nearly half of drivers (45%) being in favour of it, while (44%) were still hesitant and 11% were against it. The mandatory mode was the least accepted by drivers: only 38% would definitely accept it, while 26% would not accept it.

As found with other studies, this lack of acceptability for the mandatory modes is coupled with an understanding that this would be the most effective mode in terms of safety. Drivers indicated that mandatory ISA would be more acceptable if it was installed in all vehicles and if speed limits were more adapted to the road. The researchers indicated that improvements in the accuracy and reliability of the system would also undoubtedly increase acceptance.

The social representation of speed was found to mediate the acceptability of the voluntary ISA. Prudent drivers would accept this mode more than the other drivers, as it enabled them to know the exact speed at which they were travelling. The Pragmatists were the least likely to acknowledge the usefulness of this mode, and in the case of the Defiants and the Hedonists, driving with this mode was not very pleasant and afforded them less pleasure than their normal mode of driving.

There was no significant difference between the four groups of drivers as regards the acceptability of the other two modes. However, the results showed clearly that the mandatory mode was overwhelmingly rejected by all the drivers, whichever group they belonged to.

With regards to the calculations of speed and resulting safety benefits, the 90 participants made almost 16,000 trips in the 20 vehicles adapted for the trial, driving a total of 130,000km. Speed and acceleration were recorded at 2Hz. The speed distribution for the advisory mode was only slightly different from the baseline distribution (a reduction of mean speed over all network types of 0.8km/h). A reduction of 2km/h was observed for the voluntary mode, and 1.4km/h for the mandatory mode. The speed distributions for the voluntary and mandatory modes were more peaked around the speed limit and there were fewer excessive speeds.

The methodology for estimating the safety benefits used a simulated traffic environment in which all passenger cars were equipped with the LAVIA system. The simulation process involved:

1 estimating injury risk as a function of impact severity

2 deriving the travel speed of all injury-crashed vehicles, assuming the total vehicle fleet was fitted with the LAVIA system

3 estimating the likely travel speed distribution of vehicles that crashed, using the speed distributions observed from the LAVIA sample in the field.

Reductions were calculated for frontal and side impacts, which comprised 80% of all fatal and serious-injury car crashes in France. The energy equivalent speed (EES) distributions associated with the travel speed distributions of crash-involved vehicles, for each LAVIA mode and for each road network type, were estimated. These distributions were then multiplied by the risk of sustaining serious (MAIS 3+) or fatal (MAIS 6) injuries for each type of impact (frontal and side), so that it was possible to calculate the safety gains for a given road network, impact type and LAVIA mode. Table 3.4 shows the results of the safety gain estimation calculations. The LAVIA mode ‘neutral’ is used as a reference (ie where vehicle data was collected but no ISA was available to the driver). The values represent the percentage of car occupants’ fatalities that could be avoided if all vehicles were equipped with a LAVIA system, for the specific mode shown and a given road network.[5] A limitation of this study is the lack of control group, which means that not all of these crash reductions can be attributed to LAVIA.

Table 3.4 LAVIA safety gain estimation calculations

Network type	ISA mode	Frontal impact		Side impact	
		MAIS 3+	MAIS 6+	MAIS 3+	MAIS 6+
Urban	Advisory	4%	4%	3%	4%
	Voluntary	11%	14%	1%	3%
	Mandatory	9%	11%	0%	n/a
Interurban	Advisory	2%	5%	0%	7%
	Voluntary	3%	8%	9%	17%
	Mandatory	2%	8%	8%	6%
Motorway	Advisory	3%	7%	n/a	4%
	Voluntary	6%	13%	5%	16%
	Mandatory	5%	13%	4%	16%

The voluntary ISA mode appears to have had the same (if not more, in some cases) levels of benefit as the mandatory ISA. The effects of the advisory system were smaller, although not insubstantial. The researchers explain the similar benefit level of the voluntary and mandatory systems as being due to the fact that drivers generally chose to activate the voluntary ISA. However, the data also suggests that drivers’ use of the kick-down function increased over time, and given that the participants always used the voluntary ISA before the mandatory ISA, a bias in the data may have occurred. In effect, the results may have overestimated the effect of the voluntary ISA. It should also be noted that the procedure only modelled injury risk to vehicle occupants; effects on vulnerable road users were not included.

[5] These estimations are only valid for crashes involving passenger vehicles in which an occupant is seriously or fatally injured in a frontal or side impact. The safety benefits for other road users and other car crash types have not been estimated here.

3.4 NSW Centre for Road Safety (Australia)

This trial installed advisory ISA in 104 vehicles operating in the Illawarra region of New South Wales (NSW Centre for Road Safety 2010b).Nine hundred and thirty-two speed zones and 452 curve advisory signs were mapped. The baseline period lasted for approximately one month before activating ISA. The ISA period lasted three months and was followed by a second baseline of two months' duration. Data was captured every 10 seconds. Qualitative and quantitative attitudinal work was also undertaken with drivers and fleet managers. The total distance travelled by the test vehicles was 1.91 million kilometres.

When ISA was installed, 85% of the vehicles spent less time travelling at 5km/h over the speed limit. It was also effective at reducing excess speed (up to 20km/h over the speed limit). There was a speed reduction observed across all speed zones, with the largest reductions on 110km/h zones (a 3.22km/h reduction) and a smaller 0.82km/h reduction in 40km/h zones. Generally, speeds increased once ISA was deactivated, but in most cases did not return to the original level. Young drivers were less likely to reduce their speeding and admitted to turning off the device more frequently than other drivers. The report (NSW Centre for Road Safety 2010b) does not make any reference to the effectiveness of the curve-warning function. By applying Nilsson's Power Model (Nilsson 2004) to the speed reductions observed, the researchers estimated an 8.4% reduction in fatalities and a 5.9% reduction in injuries.

The attitudinal work concluded that participants were generally positive regarding the benefits of advisory ISA, particularly for other drivers and especially other young drivers. It was also seen as beneficial as an aid to knowing the speed limit, but participants would have preferred some leeway in the system so that minor excursions over the speed limit were allowable. Participants were particularly favourable to its functionality around schools, but demonstrated more mixed responses to the curve warnings. This was partially due to the audible warnings being seen as annoying and could lead to drivers disengaging the system. They were understood as a 'necessary annoyance', but participants suggested that improving the interface further could improve its effectiveness.

The Centre for Automotive Safety Research used the data obtained from the trials carried out in New South Wales to model the likely crash savings if ISA were to be implemented in government fleet vehicles. The following two scenarios were modelled:

1. The ISA device is transferred from a vehicle that is about to be sold to a new government vehicle, in order to keep it within the government fleet.
2. The advisory ISA is left in the government vehicle when it is sold.

Kloeden's risk curves (Kloeden et al 2002, cited in NSW Centre for Road Safety 2010b) were applied to the speed data collected in the baseline and ISA phases of the New South Wales trial. This data was first weighted by speed to produce distance-based measurements to convert to a risk per distance travelled. Speeds below 75% of the speed limit were not included in the analysis (as the risk curve is relatively flat). The authors estimated a 20% reduction in government vehicle casualty crashes, ranging between 2% and 70% depending on the speed limit zone, with a monetary saving of $31.6 million.

The benefit–cost ratios (BCRs) were then calculated across four different ISA devices.[6] A navigation device that included ISA functionality was found to have a payback period of approximately one year, with the other devices having longer payback periods, depending on the scenario.

[6] The authors recognise the limitation of using the speed data obtained from only one type of device in the New South Wales trial and then applying that data across the board to the other devices.

3.5 Pay As You Speed (PAYS) (Denmark)

This Danish project focused on simulating a market introduction of ISA equipment (Lahrmann et al 2012, pp10–16). Drivers aged between 18 and 24 were recruited and offered a financial reward for their participation in the project, called 'Pay As You Speed' (PAYS). The overall purpose of the PAYS project was to investigate whether an insurance discount would motivate young, inexperienced motorists to install ISA equipment in their cars (see figure 3.6). A display was provided within the vehicle, showing the current speed limit and the number of penalty points accrued during the current trip. The aim was to recruit 300 drivers to the trial.

Figure 3.6 In-vehicle display device (Lahrmann et al 2012)

If the vehicle exceeded the speed limit by more than 5km/h, a verbal reminder of the speed limit was provided and repeated every six seconds until the speed dropped below the speed limit (+5km/h). Following the second warning, the driver was told 'You are driving too fast' and penalty points were displayed every six seconds. The number of penalty points per warning was related to the level of excessive speeding: between 5 and 20km/h over the speed limit, 1 penalty point every six seconds was imposed; 20–30km/h above the speed limit, 2 penalty points were imposed; and so on.

Participants were offered a discount of up to 30% on their car insurance premiums as an incentive to join the trial, to be paid retrospectively every six months. They had €0.07 deducted from that bonus for each registered penalty point during that period.

When recruitment started in September 2005, 6000 young car owners between 18 and 24 years of age in North Jutland were contacted by mail, supplemented by media coverage. However, only 40 drivers responded, and market research revealed that participation was hampered by the recording of speeds and the initial fee (which was out of line with the insurance they were paying). Additional funding was secured and a new round of recruitment, offering free participation, started in February 2006. The upper age limit was raised to 28 and 11,400 car owners in North Jutland County were mailed, resulting in 230 positive responses and culminating in 50 contracts being signed (0.5% participation rate). Following that, the age limit was completely lifted (yielding another 30 drivers), the insurance company recruited some additional participants, and Aalborg University staff were also targeted. By December 2007 a total of 153 contracts were signed (equal to one per 1000 car owners in North Jutland County).

The first participants had the equipment installed in autumn 2006 and the last group had the equipment installed at the end of December 2007. Drop-outs meant that only 105 systems were in operation by this point.

The field trial was subdivided into the following 18 successive periods of 45 days:

1. Baseline phase 1 (1 period): The ISA system was actively logging data from the participants' cars, but the participants did not receive any speed information from the system.
2. Experimental phase (3 periods): Participants were randomly assigned to one of four groups, which varied in the type of speed information they received (see table 3.5).

3 ISA phase (13 periods): All the participants experienced the ‘combination system’ described in table 3.5.

4 Baseline phase 2 (1 period). The ISA system was actively logging data from the participants’ cars, but the participants did not receive any speed information from the system.

The second phase was used to establish whether the effects of the informative function of ISA were separate from the incentives for not speeding. This was achieved by splitting the sample four ways, as shown in table 3.5.

Table 3.5 Participant groups (Lahrmann et al 2012)

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Incentive</th></tr>
<tr><th>-</th><th>+</th></tr>
<tr><td rowspan="2">Information</td><td>-</td><td>Control group
No information – no warning
No penalty points if speeding</td><td>Incentive group
No information – no warning
and penalty points if speeding</td></tr>
<tr><td>+</td><td>Information group
Information about speed limit –
warning if speeding
but no penalty points</td><td>Combination group
Information about speed limit –
warning if speeding
and penalty points if speeding</td></tr>
</table>

In the third phase (ISA phase), all drivers had the combination system available.

The data from 146 drivers was entered into the analysis, logged at 1Hz, over 2.9 million kilometres. Four measures of speed were calculated and compared across the different conditions:

- proportion of distance above the speed limit +5km/h (PDA)
- mean free-flow speed (MFFS)
- standard deviation speed
- 85th percentile free flow speed (85th percentile).

Using the data gathered in the ‘experimental phase’, the effects of the four PAYS systems (table 3.5) were compared. There was found to be a statistically significant reduction (3–5%) in overall PDA with information and incentives, compared with the first baseline period. Similar trends were found for 85th percentile speeds, with the combination demonstrating a 7km/h reduction on 80km/h roads. For 50km/h roads, the reduction was in the order of 3km/h for both groups. The effects on mean speed were less clear, with only the combination and information groups demonstrating reductions, on 80km/h roads. This was coupled with a reduction in standard deviation speed. There was no systematic effect of time across the three phases on any of the measures.

The researchers felt that the measure of PDA provided the most precise description of the ISA effect and thus this measure is focused on below.

In the ISA phase where all drivers had the combination system, the PDA declined from 13% in the baseline period to around 4% in the first (of the 13) ISA period. There was then a slight increase over the 13 periods, especially on 50km/h roads. In the second baseline period at the end of the trial, the PDA increased back up to the level in the first baseline period.

No significant effects of gender were found, although young drivers had a higher PDA in both of the baseline periods, compared with older drivers. However, the effect of ISA on these two groups was similar in the ISA phase.

In summary, providing information to drivers about their speeding and using a financial incentive resulted in reductions in speeding, but these interventions had no additive effect. Of the two methods, providing the information was the more effective. However, these effects decreased over time, and when ISA was inactive the drivers returned to their original level of speeding. It should be noted that the low number of participants was a limitation of this study and the participants may not have been representative of the whole driving population.

3.6 Intelligent Speed Adaptation (ISA) in Company Vehicles (Denmark)

This project, undertaken in 2008 by Agerholm, Waagepetersen, Tradisauskas and Lahrmann, investigated the impact of ISA on professional drivers by combining information about speeding with an incentive, which was a monthly award for those who had the fewest speed violations (Lahrmann et al 2012, pp17–28). The project was based on the PAYS project, albeit with slightly different technology. However, the interface was very similar in terms of when and how the warnings were provided. The penalty points were shown on the display and summarised for each driver. Once a month the driver with the fewest points won an award sponsored by the local municipality. Each driver owned a personal ID key, which had to be in contact with the display when initiating a trip. A total of 345,000km were covered by drivers in this trial.

Twenty-six commercial cars and 51 drivers were involved in the trial over the course of one year (2007–2008). The experiment ran over 14 months, with the first two months being a baseline period. Speed and the speed limit were logged every second, and in the 14 months participants drove 370,000km.

The authors reported differences in the amount of time drivers used the ID key that stored the penalty points and thus provided the incentive. Only 44% of the distance was driven when the drivers had identified themselves via the ID key, compared with 62% in the baseline period. There were only 16 drivers (out of the 51) who drove the majority of their mileage under identification. When drivers did identify themselves, only 4% of the mileage was driven over the speed limit (+5km/h), compared with 20% when the driver had not identified himself.

Average speeds on roads with a speed limit of 80km/h decreased from 80km/h to 76km/h when the participants identified themselves, while the speed of the participants who did not identify themselves rose slightly over the project period. A questionnaire revealed that those drivers who did not identify themselves were, on average, 11 years younger, displayed more of a positive attitude to speeding, and had a negative attitude towards ISA, compared with the other drivers. The authors concluded that the project provided no reason to believe that ISA in company cars was a technology that companies would be keen to introduce, as drivers of company cars would be reluctant to use ISA voluntarily. However, companies would have the option of enforcing its use.

3.7 Ghent ISA Trial (Belgium)

Thirty-four cars and three buses were equipped with an active accelerator pedal in a trial that ran from 2002 until 2004, in the City of Ghent (Vlassenroot et al n.d.). This system had a ‘force feedback’ function, supplying mechanical resistance to the accelerator pedal.

Overall, average speeds showed little decrease when the pedal was active, apart from in the 90km/h zone (a reduction of 1.1km/h). There were some small observed increases in speed in urban areas (0.7km/h). Speed violations decreased when the active accelerator pedal was operational, particularly in areas with higher speed limits. There were large between-driver differences, with the proportion of the distance over which drivers were speeding *without* the ISA system varying between 6% and 61%, compared with 3% and 50% *with* the ISA system.

After the trial, the drivers could choose to keep the system in their car and 15 (44%) chose to do so.

3.8 Speed Choice and Modelling the Impacts of Speed on Safety and the Environment (Transport Canada)

This trial evaluated the following two ISA systems on 20 private and commercial vehicles (10 with each system):

- the Imita SA (Lund) system, which had a repetitive audio tone with a flashing speed limit display warning, plus a haptic[7] feedback through the accelerator pedal when the speed limit was exceeded
- the OttoMate system(supplied by Persen Technologies Ltd), which used a voice message and flashing light as feedback when the speed limit was exceeded.

The trial took place between 2005 and 2006 and a total of 85,413km and 28,764km, for private and commercial vehicles respectively, were recorded. Outcome measures included the number of speed violations compared with the number of 'before' and 'after' violations during the respective baseline periods. A total of 70 individual vehicle/trial period observational datasets were created. The initial baseline period lasted one month, followed by use of the audio-visual feedback (one month), then haptic feedback for the Imita-equipped vehicles only (one month), and finally a second baseline period (one month). The short duration of this study was a limitation.

With the Imita audio-visual feedback in the private vehicles, speed violations decreased by 12% overall (8% in the 80km/h zone and 15% in the 100km/h zone), but there was no further change in the haptic stage, (although there were decreases within some of the PSL[8] zones). In the commercial vehicles, speed violations were reduced in both the audio-visual and the haptic feedback modes, with the haptic method achieving larger reductions. The (haptic) change was largest in the 100km/h zone, where violations dropped from 23% to 14%.

With the private vehicles equipped with the OttoMate system (which sounded a warning only as the speed limit was broken, rather than making a continuous sound at any speed above the speed limit), it appears that during the audio-visual feedback stage there was an increase in speed violations (50% to 54%), particularly in the 100km/h zone (54% to 68%). However, these over-speeds were relatively small (0–10km/h). These increases may have been due to annoyance with the repeated warnings (as some respondents noted in the questionnaires), and drivers commented that they intentionally drove over the speed limit to avoid having the reminder being played frequently.

[7] Tactile feedback technology that takes advantage of the sense of touch by applying forces, vibrations or motions to the user.

[8] Posted speed limit.

3.9 SafeMiles project (Transport Canada)

In 2006, the Dutch government transferred the hardware and software used in their 2005 Belonitor project to Transport Canada so that a replication of that trial could be undertaken (Taylor et al 2010). This transfer included 55 in-vehicle systems, the use of the software developed for the vehicle, and rewards to be given to participants based on their compliance with speed limits and vehicle headway. The rewards consisted of points that were redeemable for goods and services.

The project consisted of three phases. The first baseline period ran for two weeks (n=41).The 'points phase' of the trial ran for almost three months, during which time the participants received feedback on their driving habits, allowing them the chance to improve their safe-driving skills. The feedback provided the participants with speed and headway compliance or non-compliance icons, with a green LED indicator during compliant driving and a yellow indicator during non-compliant driving. The total points accumulated during a trip were displayed when the vehicle came to a stop for at least five seconds, and the total points earned during a trip were displayed to the participants after the vehicle's ignition was turned off. The final phase of the trial ran for two weeks, during which time the device was switched off again. There were no points displayed, no icons, and no LEDs illuminated during this period.

A total of 275,655km of driving was observed, of which 234,480 were within the area covered by the speed limit map. Speed compliance rates in all speed limit zones improved significantly and indicated stable performance throughout the feedback period. Overall compliance was 74% in the first baseline period, 94% in the feedback period, and 86% in the second baseline period. During the second baseline period, males reduced their speeds slightly more than females. The 30–39 age group exhibited the largest change in compliance during the feedback period. The highest rates of compliance during the feedback period occurred in the 100km/h zones and the lowest compliance rates were in the 50km/h zone. Males aged 20–29 lost all of their 'gains' from the feedback stage.[9]

The data also allowed the investigation of 'abrupt braking events' (ABE), which were defined as being greater than (12.6km/h/s)[10] and were taken as a proxy for a near collision. Across all participants and between the phases, there was no statistically significant change in the average ABE rates (although males had approximately double the rate of females).

The questionnaires indicated that the participants had an overall high level of acceptance of the system and believed that the system should be more widely applied.

3.10 Summary

Research into ISA in recent years has moved away from focused experimental work, with efforts now being much more focused on how particular variants of ISA may be used in specific scenarios by different types of drivers. Much of the pre-2005 research concluded that whilst advisory ISA was more accepted by drivers, it did not deliver in terms of safety benefits, mainly due to drivers choosing not to engage the system. A large proportion of that research has been reported in a special issue on ISA in *Accident Analysis & Prevention 48* (2012). Post-2005, research has tended to lean towards trials that are more focused on deployment, in the sense that there have been a number of partnerships between insurance companies, companies that run fleets of vehicles, and local authorities. However, given the general

[9] The report also detailed the results from the headway advice feedback function, but these are not reported on here.

[10] The same value was used in the Dutch trial.

reluctance to install a mandatory ISA, there is a tendency for users to use the system only when they wish to.

The research issue thus becomes more one of incentives and acceptance, which the Danish project attempted to tackle. That project concluded that providing speed information was as successful as providing incentives, if not more so. However, the effect of such information weakens over time, and this is a finding that can be found across a range of speed countermeasures. We know from attitudinal work that habit or past behaviour is a very strong predictor of future behaviour (intentions); although drivers may genuinely be supportive of ISA and even show high levels of engagement, as time goes by or when the intervention is removed, drivers revert to behaviour that is guided by automated cognitive processes, rather than behaviour based on attitudes and intentions. How do we break this habit in a way that is acceptable to drivers?

An adaptive system that supports a driver in an intelligent way would be more acceptable and effective than one that is either inflexible, such as mandatory ISA, or an ISA with an easy opt-out. Both of these would have limited appeal or safety benefit for those drivers who speed regularly, inadvertently or otherwise. We envisaged a number of ways of making ISA systems more flexible and acceptable to drivers and investigated these with focus groups and trials, as reported in chapters 7 and 8, as well as a ‘think piece’ in chapter 4 on encouraging uptake.

While this literature review suggests that a long-term study would be beneficial for monitoring ISA use and speed compliance over time, the scope of this research has been limited by budget constraints. However, this research is an important first step in investigating the deployment of an advisory ISA in New Zealand and while a long-term field trial has not been undertaken, this study has investigated the issues and institutional barriers associated with the deployment of an advisory ISA system.

4 Encouraging uptake

4.1 Context

In terms of incentives to encourage the uptake of ISA, we can differentiate between two areas of interest. The first relates to encouraging drivers to either purchase a vehicle with a speed-limiting device or to retrofit their vehicle with this function if that option is available to them. This relies on drivers being accepting of such technology if we assume they intend to use it, or that someone is accepting of it on their behalf (eg a parent or a fleet manager). The second area of interest relates to a driver's willingness, in the case of an advisory ISA, to turn the function on and comply with the information.

A project was carried out by the University of Leeds on behalf of the Motorists' Forum, aiming to model the safety and emissions savings that could be gleaned via a voluntary ISA (Chorlton et al 2011). Part of the project also focused on how drivers could be encouraged to purchase a vehicle that had voluntary ISA. These results are briefly outlined here, and then the implications for further work are presented.

4.2 Leeds choice modelling experiment

A face-to-face stated preference (SP) survey of drivers was carried out on almost 1500 drivers in the UK. SP is a survey technique used to understand individuals' preferences and how they use those preferences to make choices. The SP can explore how individuals respond to a range of choices to establish a 'willingness to pay' (WTP), or a willingness to accept payment, for a particular benefit. In a SP survey, individuals are presented with a number of choice sets or scenarios, and asked to choose one option from each of the choice sets. The approach involves the description of goods or services in terms of underlying attributes (such as cost, style, features, etc). The method is referred to as the 'stated preference' method because individuals are asked to directly state their choices. By creating hypothetical (but realistic) scenarios, it is possible to explore those factors influencing choices related to a product, such as ISA, that is not yet available on the public market, and also to identify any important differences between subgroups in their preferences. This method is routinely used to establish the cost of injury, using a willingness-to-pay approach.

From some pilot work, it became obvious that drivers varied in their willingness to pay for ISA, and so the following three separate survey designs for three broad groups of drivers were created:

1 Those who would buy a mandatory ISA system: These drivers received a SP survey where both systems were offered at a cost to the driver (Group 1 – 490 respondents).

2 Those who would buy a voluntary system: Drivers were required to pay for a voluntary system but received incentives to buy a mandatory system (Group 2 – 503 respondents).

3 Those who like neither system: Both systems were offered with discounts and incentives to encourage drivers to purchase an ISA vehicle (Group 3 – 466 respondents).

The factors that influence decisions to buy that were investigated were purchase price, insurance discounts and annual tax discounts. Incentives to use voluntary ISA that were studied were a fuel rebate, or cash back on a driver's insurance premium for every mile travelled with the system activated. Four other factors were also investigated:

- the percentage of other equipped vehicles on the road
- free optional extras on a new car

- varying the penalty administered for committing a speeding offence
- varying the length of time speeding endorsements remained on a driver's licence.

Respondents also supplied demographic and driving history information.

4.3 Choosing between voluntary and mandatory ISA

One useful way to view the results is to consider what it would take for equal willingness to purchase either system.

Respondents in Group 1 were given a set of situations in which they had to pay for both types of ISA, but some incentives to use the voluntary system were offered. The overall finding for this group was that a price of £600 for the voluntary system, together with a 1p/mile fuel rebate, was equivalent in attractiveness to a price of £636 for the mandatory system. This showed that this group was willing to pay more for mandatory ISA. Further analysis showed that Group 1 was quite heterogeneous, with four identifiable subclasses – those for whom:

- a price of £423 for the mandatory system was equivalent to a price of £600 and a 1p/mile fuel rebate for voluntary ISA
- a price of £1296 for the mandatory system was equivalent to a price of £600 and a 1p/mile fuel rebate for voluntary ISA
- a price of £323 for the mandatory system was equivalent to a price of £600 and a 1p/mile fuel rebate for voluntary ISA
- even a free mandatory system was not equivalent to a price of £600 and a 1p/mile fuel rebate for voluntary ISA.

The respondents in Group 2 were required to pay for a voluntary ISA and were offered a hypothetical discount to persuade them to choose a mandatory ISA instead. Again, there were incentives offered for using the voluntary system. Three reliable subclasses emerged – those who had:

- a preference for the mandatory system and for whom a discount on the mandatory system was only required to make it equally attractive if the voluntary system cost less than £530 with a 1p/mile fuel discount
- a dislike of the mandatory system so extreme that any realistic levels of discount would not be sufficient for the mandatory system to be as likely to be chosen as the voluntary system
- an equal probability of choosing either system if the voluntary system cost £600 and the mandatory system had a discount of £1450.

Group 3 respondents were offered a hypothetical discount for purchasing either system as well as incentives to use the voluntary system. The following three subclasses emerged:

- Those with a very strong preference for the voluntary system: The preferences in the group were so extreme that no reasonable shift in discounts would lead to the two systems being equally attractive.
- Those with a strong preference for the mandatory system: The preference for the mandatory system was so large that with no discount for that system, a discount of £769 on the voluntary system, along with a 1p/mile fuel discount, would be required to make the two systems equally attractive.

- Those with relatively even probabilities of choosing one or the other system: If there was a 1p/mile fuel discount but no price discount on the voluntary system, a discount of £2040 would be required on the mandatory system for it to be equally attractive.

4.4 Purchase decisions

Separate models were estimated for the two systems. However, it was recognised that the attributes of one system potentially had an effect on the stated intention to buy the other system. Therefore the attributes of both systems were included in both sets of models. There was ‘pollution’, such that respondents considered their response regarding one system in the context of the other (eg perhaps choosing the lesser of the two evils). The alternatives examined were the decision to buy or not buy each system.

In general, overall modelling by respondent group (ie segmenting the drivers) worked. Subclasses within the groups could be identified, but the overall findings were consistent with those of the more aggregated modelling. Increases in cost could decrease the probability of buying a specific system but increase the probability of buying the alternative system. For Group 1, the statistical model fit was better for the (preferred) mandatory system than for the voluntary system. The cost of the mandatory system was a more significant factor in the purchase decision than the cost of the voluntary system. As an incentive to use the voluntary system, fuel rebates and insurance cash-backs had a positive impact on the probability of buying the voluntary system, but had the opposite effect on the probability of buying the mandatory system. Even if the voluntary system was free, with a fuel rebate of 1p/mile, the mandatory system could cost up to £273 before the probability of buying a vehicle with the mandatory ISA installed would drop below 50%. However, with the costs of the voluntary system at £600 and £1200, the maximum acceptable prices for the mandatory system were below those of the voluntary system, at £541 and £810 respectively. This was a result of the asymmetry in the sensitivity to costs for the two systems. Looking at the probability of buying the voluntary system, again at no cost and with a fuel rebate of 1p/mile, the mandatory system would have to cost more than £775 before the probability of buying the voluntary system exceeded 50%. With costs of the voluntary system at £600 and £1200, the minimum price for the mandatory system would be £987 and £1199 respectively. This means that up to a price of £1200, the cost of the voluntary system would need to be below that of the mandatory system for the probability of buying it to exceed 50%.

For Group 2, if the voluntary system was free and had a fuel rebate of 1p/mile, the mandatory system would have to have a discount of at least £2818 before the probability of buying it rose above 50%. This dropped to £1788 and £757 when the cost of the voluntary system was increased to £600 and £1200 respectively. On the other hand, looking at the probability of buying the voluntary system, again at no cost and with a fuel rebate of 1p/mile, if the mandatory system was to come with a discount of less than £140, then the likely decision would be to purchase the voluntary system. With higher costs for the voluntary system, the probability of purchase was less than 50% even without discounts for the mandatory system. These values changed significantly with higher rates of fuel rebate.

For Group 3 (who liked neither system), the probability of buying either system was very low. However, with no discount for the voluntary system and no fuel rebate, a discount of £7936 would be required for the mandatory system to have a probability of 50% of being purchased. If a free entertainment system was provided, the required discount dropped to £5566. This drop was higher than expected and gave an indication of the high protest vote associated with the mandatory system. For the voluntary system, a discount of £2838 would be required for the probability of buying it to exceed 50%; fuel rebates and insurance cash-backs had no statistically significant effects.

4.5 Conclusions

The survey results revealed that there were considerable variations in sensitivities and preferences in the sample. The main differences were between the three groups already identified before the survey questionnaire was administered. However, even within the groups there were major variations, such that models of choice between the two systems performed much better when subclasses within the groups were considered.

Group 1, who preferred the mandatory system, were willing to pay considerably more for a mandatory ISA than for a voluntary one. Group 2 would generally be willing to purchase a voluntary ISA with only a modest subsidy, provided the cost was not very large. Within Group 2 (who were supposed to prefer the voluntary system), one subclass actually preferred the mandatory system without a discount even over a voluntary ISA with a considerable incentive. Another subclass could not be persuaded to choose a mandatory ISA under virtually any realistic subsidy. And a final subclass would choose either system at equal probability if a voluntary ISA cost £600 and a mandatory ISA had a discount of £1450 – ie they hugely preferred the voluntary system. Group 3, who nominally did not like either system, was also heterogeneous. Their general probability of buying either system was confirmed to be low, but when they had to choose one version over another, three subclasses emerged: one would always choose a voluntary ISA; one had a very strong preference for mandatory ISA (perhaps indicating that if one had to have ISA, one might as well have the stronger form); and one had roughly equal preference for the two variants.

Therefore the picture is of some groups with very entrenched positions (both pro and anti) who were not really amenable to persuasion by means of incentives. On the other hand, there were other groups who were amenable to subsidy, particularly on purchase price and fuel cost, or who would be willing to purchase an ISA system if the cost was not too high. It is interesting to note that the analysis revealed that while there were very significant variations in sensitivities and preferences, these could not easily be linked to socio-demographic attributes of the respondents. As such, it is not necessarily the case that young male respondents had a strong objection to ISA while older respondents with more expensive cars had a more positive attitude. This observation would suggest that the people surveyed had strong inherent views on installing an ISA in their car, independent of their socio-demographic characteristics, and that as a consequence, it would not be easy to target one specific part of the population in a campaign to increase the uptake of such systems. Refer to Chorlton et al (2011) for further information.

4.6 Implications for the New Zealand focus groups

This section provides a 'think piece' on incentives that could encourage ISA uptake. This indicates a number of potential implications and approaches that should be considered for the New Zealand focus groups (see chapter 7).

1. Consideration of moral hazard: For example, using data from the Quebec public insurance plan, Dionne et al (2011) analysed the effectiveness of point demerit systems on promoting safe driving. They found evidence of moral hazard, meaning that drivers who accumulate demerit points become more careful because they are at risk of losing their licence. How could this idea be used effectively with regards to the marketing and uptake of ISA?
2. A softly-softly approach, whereby ISA is introduced in a gradual way: This could either be in a geographical sense (ie where benefits are more obvious to the driver, such as in urban areas) or in the 'severity' sense (ie the speed restriction becomes stricter over time).

3 ‘Human/machine’ interfaces: Further work is needed on appropriate ‘human/machine’ interfaces. Simply presenting the advised speed seems not to work in the long run and so consideration should be given as to whether this would be more effective if combined with other information, eg fuel consumption or likely carbon footprint. Different information is likely to be more effective for different segments of the population.

4 Information/warning systems: Consideration should not only be given to *what* type of information/ warning should be presented, but also how it should be presented in terms of frequency, etc. Evidence in psychological literature suggests that partial reinforcement is more effective than reinforcement that is provided after every instance of positive behaviour. Another manipulation might be how much time must elapse before the driver gets rewarded for performing the desired behaviour. Drivers may be more responsive to ratio schedules that vary the presentation of rewards (variable ratio schedules) due to the continuous possibility that a reward might be around the corner (even if they were just rewarded a few minutes ago).[11] In terms of ISA, the time period for the reward structure (eg minutes/miles of speed violation avoidance) could be varied.

5 Incentives: Should incentives take the form of a reward schedule (for travelling at or below the speed limit) or should there also be a negative schedule for when drivers exceed the speed limit?

6 Removal of incentives: What happens when the incentives are removed? Many of the trials reported a decrease or total cessation in the effects of an ISA system once it was removed. Again referring to psychological literature, if reinforcement has been continuous, the extinction effect is very fast. On the other hand, following partial reinforcement the extinction effect is typically very slow.

[11] The behaviour of gamblers in situations where rewards are often rare (and inadequate) suggests that for some people, very persistent behaviour may be maintained by rewards that are extremely infrequent.

5 A suitable speed limit system

5.1 Introduction

The overarching purpose of this research project was to investigate the issues associated with the deployment of an advisory ISA system in a New Zealand context.

All ISA systems researched to date have as their starting point the need and ability to inform drivers about the fixed speed limits that apply to the area they are driving in. While it is possible to have a road-based ISA system that uses transponders (or similar) technology such as sign recognition systems, the research reviewed here has favoured GPS/navigation-based systems. Therefore a key component of the deployment of ISA in New Zealand is the development of a comprehensive and accurate national electronic speed limit management system or map to underpin the ISA system. This requirement may change as technology advances and the cost of other systems, such as sign recognition, decreases.

Currently, map providers in New Zealand supply users with speed zone information via in-car navigation devices. This data is predominantly sourced by the map providers themselves and is sometimes complemented with data from road controlling authorities (RCAs). However, these current arrangements do not provide an efficient solution and are unlikely to be sufficient in terms of coverage, currency and accuracy of the data for a reliable nationwide ISA system, as the regularity of updates is likely to be variable and unlikely to be in real time.

This chapter explores existing speed limit management practices, and then suggests what a national speed limit management system might look like in terms of form, features and functionality. It also covers how this might be managed, as well as recommending changes to Land Transport Rule 54001 Setting of Speed Limits 2003 that would facilitate the development of such a system. Further details are contained in appendix A.

5.2 Background – setting of speed limits

The Land Transport Rule 54001 Setting of Speed Limits 2003 (Land Transport Safety Authority 2004) (the Rule) came into force in April 2004, with amendments made in 2005 and 2007. The Rule was intended to address deficiencies in the existing system that resulted from the previous complex mix of procedures and structures for setting speed limits. The Rule divided the responsibility for, and ownership of, speed limits between organisations at both central and local government level. This section outlines the main requirements of the Rule and subsequent amendments based on the September 2009 consolidation of the Rule.

Under the Rule, RCAs set enforceable speed limits on roads within their jurisdictions. RCAs are required to apply a consistent method to translate national speed limits policy into a safe and appropriate speed limit for any given road, as set out in the procedures for setting speed limits, Speed Limits New Zealand (Schedule 1 of Setting of Speed Limits 2003). Before setting a speed limit, or designating or changing an urban traffic area, an RCA must consult with persons who may be affected by the proposed speed limit and give them reasonable time to make submissions on the proposal. A speed limit is approved or changed by the NZ Transport Agency (NZTA) when the speed limit is declared by notice in the New Zealand Gazette.[12]

An RCA must establish and maintain a register of speed limits that records all speed limits (except temporary speed limits) for the roads under its jurisdiction. This register must be available for inspection by members of the public, at reasonable times, on request.

Before a speed limit comes into force on a road, an RCA must ensure that all traffic control devices installed on the road are safe, effective and appropriate for the speed limit and comply with requirements for traffic control devices (in Land Transport Rule: Traffic Control Devices 2004). This includes the requirement to place reduced speed limit signage no more than 20m from the point on the road where the speed limit change is legally defined.

Under the Rule, RCAs have an obligation to review speed limits when:

(a) There is a significant change in the nature, scale or intensity of land use adjacent to a road; or

(b) There is a significant change in a road, its environment or its use; or

(c) The RCA receives a written request to do so from the NZ Transport Agency.

The RCA also has the discretion to review speed limits if it decides to do so, or if it receives a written request from a person, organisation or road user group affected by that speed limit.

Refer to appendix section A.1 for further details on how speed limits are set in New Zealand.

5.3 Current practice and issues

To better understand the issues surrounding current speed-limit-setting and register processes, a sample of RCAs were questioned regarding the following issues that are pertinent to the establishment of a robust and maintainable electronic national speed limit system:

- how RCAs typically store their speed limit registers and make them available for inspection
- how those RCAs currently process their speed limit changes, including frequency of audits and reviews, and including accompanying signage
- any future plans for changing their current practice, such as recording of such data locally, using geospatial systems
- initial reactions to a unified national process.

5.4 Territorial Local Authority practice

To gain an understanding of Territorial Local Authority (TLA) practice, six RCAs were contacted, including Auckland Transport, which is currently amalgamating information from the seven councils that now make up Auckland Council.

The TLAs were:

- Upper Hutt City Council

[12] The official newspaper of the Government of New Zealand, published every Thursday (except over Christmas/New Year) by the New Zealand Gazette Office at the Department of Internal Affairs.

- Hutt City Council
- Auckland City Council (now part of Auckland Transport)
- Franklin District Council (now part of Auckland Transport)
- Papakura District Council (now part of Auckland Transport)
- Rodney District Council (now part of Auckland Transport)
- Manakau City Council (now part of Auckland Transport)
- North Shore City Council (now part of Auckland Transport)
- Waitakere City Council (now part of Auckland Transport)
- Dunedin City Council
- Grey District Council
- Tasman District Council.

Feedback from the RCAs is summarised below, and individual responses are summarised in appendix table A.2.

5.4.1 How speed limit data is stored and made available

All of the 12 TLAs surveyed have a speed limit bylaw with a schedule of roads. The majority (all except one contacted) have their speed limit bylaw available on the internet, and have speed limits recorded in map form. However, the method of mapping varies and can include:

- speed limit zones/areas; ie drawing a boundary with the area inside it being a certain speed limit
- speed limits attributed to individual road links
- maps annotated with position descriptions.

5.4.2 Processing of speed limit changes, including frequency of audits and reviews

Responses to this question regarding the processing of speed limit changes, including the frequency of audits and reviews, were varied in the number of items covered, and no comments were received from Auckland Transport. In general, the following points were made:

- Speed limit changes are consulted on, with a report going to council, who approve the changes.
- Consultation with the NZTA occurs, plus notification of changes to the NZTA.
- Speed limit reviews are undertaken on an as-needed/as-requested basis, with some councils undertaking reviews on a three- or five-yearly basis. One respondent stated that they only undertake reviews as required by the legislation.
- None of the respondents appear to audit speed limit sign locations in relation to the location of the gazetted speed limit.

- Dunedin City Council[13] mentioned that they have developed a rationale for setting of speed limits based on safety, use and consistency, instead of the default development-based rating. This is to reflect the Safer Journeys approach.

5.4.3 Future plans

With the exception of Auckland Transport, no RCAs were planning to make any changes to the way that they managed speed limit information. Auckland Transport was currently consolidating information from their predecessor councils into a schedule, with limited use of maps.

A number of RCAs mentioned that they had a desire to use more types of speed limits in the future, particularly school zones and 30km/h, 40km/h and 80km/h zones.

5.4.4 Initial reactions to a national system

Of the six RCAs contacted, all of them could see the benefits for a nationwide system, though half of these initially did not see the need for one until reasons were given. One RCA commented that it would be useful to have all speed limits, including state highway speed limits, on a map. Two RCAs did not have an issue with such a system, but would rather see the money spent elsewhere or questioned whether the benefit was sufficient to justify the cost.

It was commonly indicated that ‘anything that makes it easier for us is good’. This was in reference to both processing and recording speed limit changes.

Both the New Zealand Road Assessment and Maintenance Management (RAMM) asset database and a Geographic Information System (GIS) were suggested as possible vehicles for a national system, including having the ability to transfer the data between the two systems.

5.5 New Zealand Transport Agency practice

The NZTA maintains a spreadsheet-based register of all New Zealand Gazette speed limit notices on the state highway network. The register includes the region, state highway number, locality, speed limit, New Zealand Gazette reference and a description of the section of state highway eg ‘from 50m north of Mill Road to 170m south of Scarborough Street’. When changes to speed limits are made, the affected line is simply marked with strikethrough font. An excerpt of the spreadsheet is shown in figure 5.1.

[13] Pers comm, Diana Munster, Transportation Engineer, Transportation Operations, Dunedin City Council, 26 August 2011.

Figure 5.1 NZTA speed limit register excerpt

NZTA Bylaw 2010/10 Schedule 1: Speed Limits for Specified Sections of State Highway

Canterbury / West Coast State Highways

Line No.	Region	SH No.	Locality	Section of State Highway	Speed Limit (km/h)	New Zealand Gazette Reference
801	11	1	Kaikoura	From 50m north of Mill Road to 170m south of Scarborough Street.	50	1/09/2010, No 112, page 2967
802	11	1	Kaikoura South	From 175m south of Puketa Road to 1.145km north of Waitane Road.	80	1/09/2010, No 112, page 2967
803	11	1	Cheviot	From 190m north of Cadman Street to 250m south of Reeves Street.	50	1/09/2010, No 112, page 2967
804	11	1	Amberley	From 430m north of Courage Road to 310m south of Bank Street.	50	1/09/2010, No 112, page 2967
805	11	1	Amberley	From 310m south of Bank Street to 60m south-east of Grays Road.	80	1/09/2010, No 112, page 2967
806	11	1	Waikuku	From 65m north-west of Waikuku Beach Road to 60m south-west of Gressons Road.	80	1/09/2010, No 112, page 2967
~~807~~	~~11~~	~~1~~	~~Woodend~~	~~From 910m north-east of Woodend Road to 375m south of Woodend Road.~~	~~70~~	~~1/09/2010, No 112, page 2967~~
807	11	1	Woodend	From 910m north-east of Woodend Road to 375m north-east of Woodend Road.	70	20/01/2011, No 5, p 99
~~808~~	~~11~~	~~1~~	~~Woodend~~	~~From 375m south of Woodend Road to 70m north of Gladstone Road.~~	~~50~~	~~1/09/2010, No 112, page 2967~~
808	11	1	Woodend	From 375m north-east of Woodend Road to 70m north of Gladstone Road.	50	20/01/2011, No 5, p 99
809	11	1	Woodend School Zone	From 70m north of Gladstone Road to 55m south of Petries Road.	See Schedule 2	1/09/2010, No 112, page 2967
810	11	1	Woodend	From 55m south of Petries Road to 140m south of Rangiora Woodend Road.	50	1/09/2010, No 112, page 2967
811	11	1	Belfast	From 120m north of Dickies Road to the intersection with SH74.	60	1/09/2010, No 112, page 2967
812	11	1	Belfast	From the intersection with SH74 to 220m west of Connemara Drive.	70	1/09/2010, No 112, page 2967
813	11	1	Christchurch	From 220m west of Connemara Drive to 120m south-west of Ryans Road.	80	1/09/2010, No 112, page 2967
814	11	1	Christchurch	From 120m south-west of Ryans Road to 100m north-east of Yaldhurst Road.	70	1/09/2010, No 112, page 2967
~~815~~	~~11~~	~~1~~	~~Christchurch~~	~~From 50m north-east of Yaldhurst Road to 280m north of Buchanans Road.~~	~~60~~	~~1/09/2010, No 112, page 2967~~
815	11	1	Christchurch	From 100m north-east of Yaldhurst Road to 320m north-east of Buchanans Road.	60	20/01/2011, No 5, p 99
816	11	1	Christchurch	From 280m north-east of Buchanans Road to 110m south-west of Parker Street / Seymour Street.	50	1/09/2010, No 112, page 2967
~~817~~	~~11~~	~~1~~	~~Hornby~~	~~From 110m south-west of Parker Street / Seymour Street to 200m north-east of Trents Road.~~	~~70~~	~~1/09/2010, No 112, page 2967~~
817	11	1	Hornby	From 110m south-west of Parker Street / Seymour Street to 200m south-west of Trents Road.	70	20/01/2011, No 5, p 99
~~818~~	~~11~~	~~1~~	~~Rolleston~~	~~From 860m north-east of Springston Road / Rolleston Road to 300m south-west of Springston Road / Rolleston Road.~~	~~80~~	~~1/09/2010, No 112, page 2967~~

Gisborne-Hawkes Bay / Taranaki-Manawatu-Wanganui / Wellington-Nelson-Marlborough / Canterbury-West Coast / Otago-Southland / Total

The spreadsheet is stored locally at the NZTA National Office and is available to the public upon request. Updates are processed by the NZTA regions, who notify the National Office of any changes.

The NZTA has recently undertaken an exercise of auditing sign locations relative to the gazetted speed limit, and has begun using GPS coordinates in conjunction with linear referencing and location descriptions.

In the near future, the NZTA plans to develop a GIS map layer for storing state highway speed limit information.

5.6 Practice in Australia and overseas

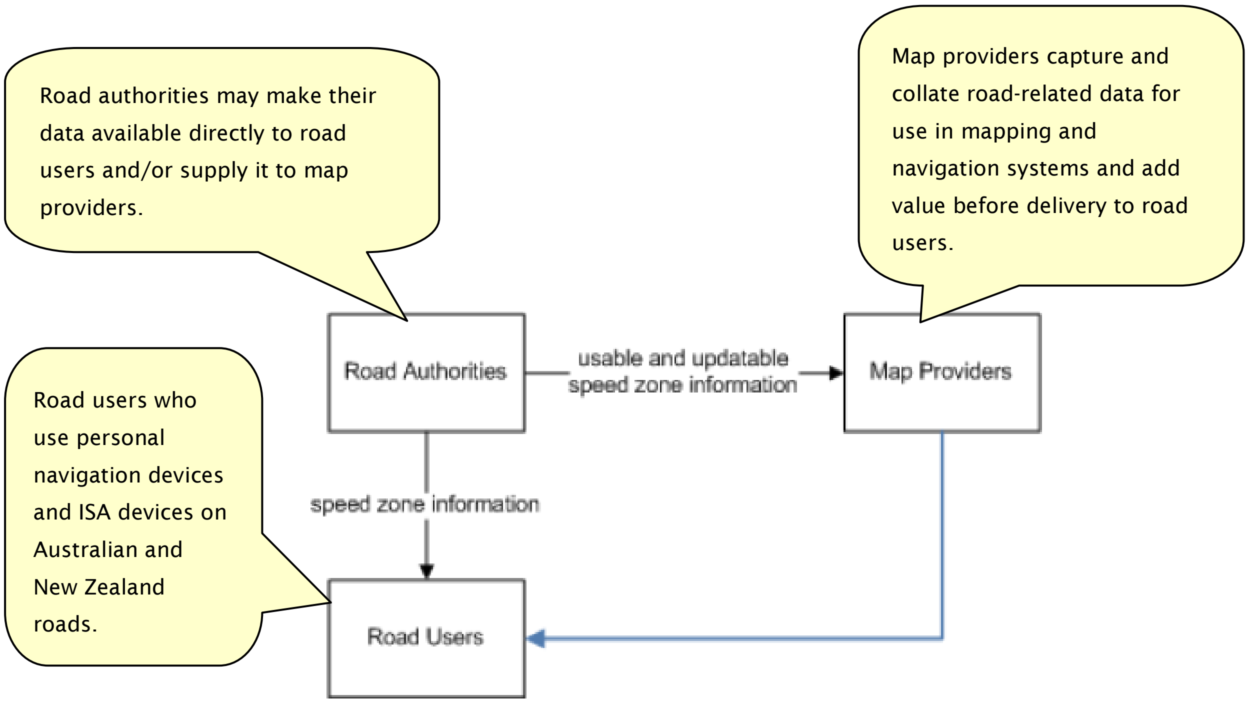
Speed limit maps are known to be in development in both Europe (MAPS&ADAS) and in Australia (ISA Connect). Key industry issues are the inefficiencies associated with map providers needing to contact many authorities, and authorities being contacted by many map providers.

5.6.1 ISA Connect

Currently in Australia, map providers supply road users with speed zone information via in-car navigation devices. This data is predominantly sourced by map providers themselves and is sometimes complemented with data from road authorities where available (and where licences have been established by the map providers).

ISA Connect is a speed zone data model that covers both Australia and New Zealand. The ISA Connect report (NSW Centre for Road Safety 2010a) looks at various models/methods for achieving this goal and discusses the issues. Figure 5.2 identifies the overall vision of the desirable outcomes for the ISA Connect project.

Figure 5.2 Overall vision for ISA Connect project desirable outcomes (sourced from NSW Centre for Road Safety 2010, with comment boxes added by the researcher)



The creation of a national dataset of speed zone data (a dataset containing speed zone information for all regions of Australia and New Zealand) that is maintained by a single authority (with contributions from multiple data providers) is not recommended. Rather, a decentralised solution that relies on each data provider to maintain and publish authoritative data (to a data service operated by a central authority) has been proposed. Such a solution is expected to result in improved efficiency, usage and quality of speed zone data by information providers and end users.

A single organisation (PSMA Australia) has been proposed as a national aggregator and distributor of speed zone information. This will help to simplify licensing arrangements and data-processing activities for map providers and road users. The framework promotes a decentralised, distributed architecture that will make national data available to the map providers and road users in a timely, harmonised, inter-operable and quality-assured manner.

5.6.2 SpeedLink

In New South Wales, a speed limit and speed signs database and e-system named ‘SpeedLink’ has been developed (NSW Centre for Road Safety2011). SpeedLink indicates the location of all authorised speed limit signs and zones, with plans for future versions to automate the associated administrative processes. SpeedLink is a comprehensive management system that includes:

- dynamic speed limit zone layers such as truck and bus zones, school zones, etc
- speed limit signs
- an authorisation process

- work instructions for signage contractors
- an ability to draw speed zones and to update information while in the field
- a search function.

Speed limit signs were included in SpeedLink because in Australia, the sign is the legal speed limit, as opposed to a set location that is notified in the Gazette, as in New Zealand.

In Australia, commercial and other options have also been considered for data storage and provision.

5.6.3 Europe

In Europe there are projects (such as MAPS&ADAS) to develop, test and validate applicable standards for gathering, certifying, maintaining and providing safety content to be integrated into safety-enhanced digital map databases, including speed alert information. This is similar to what is provided by ISA in New South Wales (NSW Centre for Road Safety 2010b).

5.7 Speed limit register practice

As described in section 5.2, RCAs have the power to set speed limits on roads under their jurisdiction. In conjunction with this power, the RCAs must also maintain a register of the speed limits. However, there is no reference made in the Rule to the accuracy required for delineating the speed limit zones. It simply states that 'a full description of the roads or area to which the speed limit applies, including references to details of maps or other documents as appropriate' is required.

Following the survey of RCAs for this research, a desktop exercise was undertaken to identify some of the different ways RCAs record their speed limit information.

An internet search was carried out covering nine different (randomly sampled) RCAs that make their speed limit information available on the internet. Table 5.1 outlines the methods by which these RCAs displayed their speed limit information on the internet.

Table 5.1 Speed limit information available from a sample of RCAs[a]

RCA	Table with spatial descriptions of speed zones	Map with spatial descriptions of speed zones	Map with no spatial descriptions
Auckland City Council (now part of Auckland Transport)	●		●
Matamata-Piako District Council		●	
Hutt City Council		●	
Wellington City Council		●	
Nelson City Council	●		●
Christchurch City Council	●		●
Dunedin City Council			●
Tasman District Council		●	
Central Hawke's Bay District Council		●	

a) The absence of a field does not mean it does not exist – just that it was not found on the website.

Examples of the three display options are shown in the following figures.

Figure 5.3 Map with spatial descriptions (example from Hutt City Council)

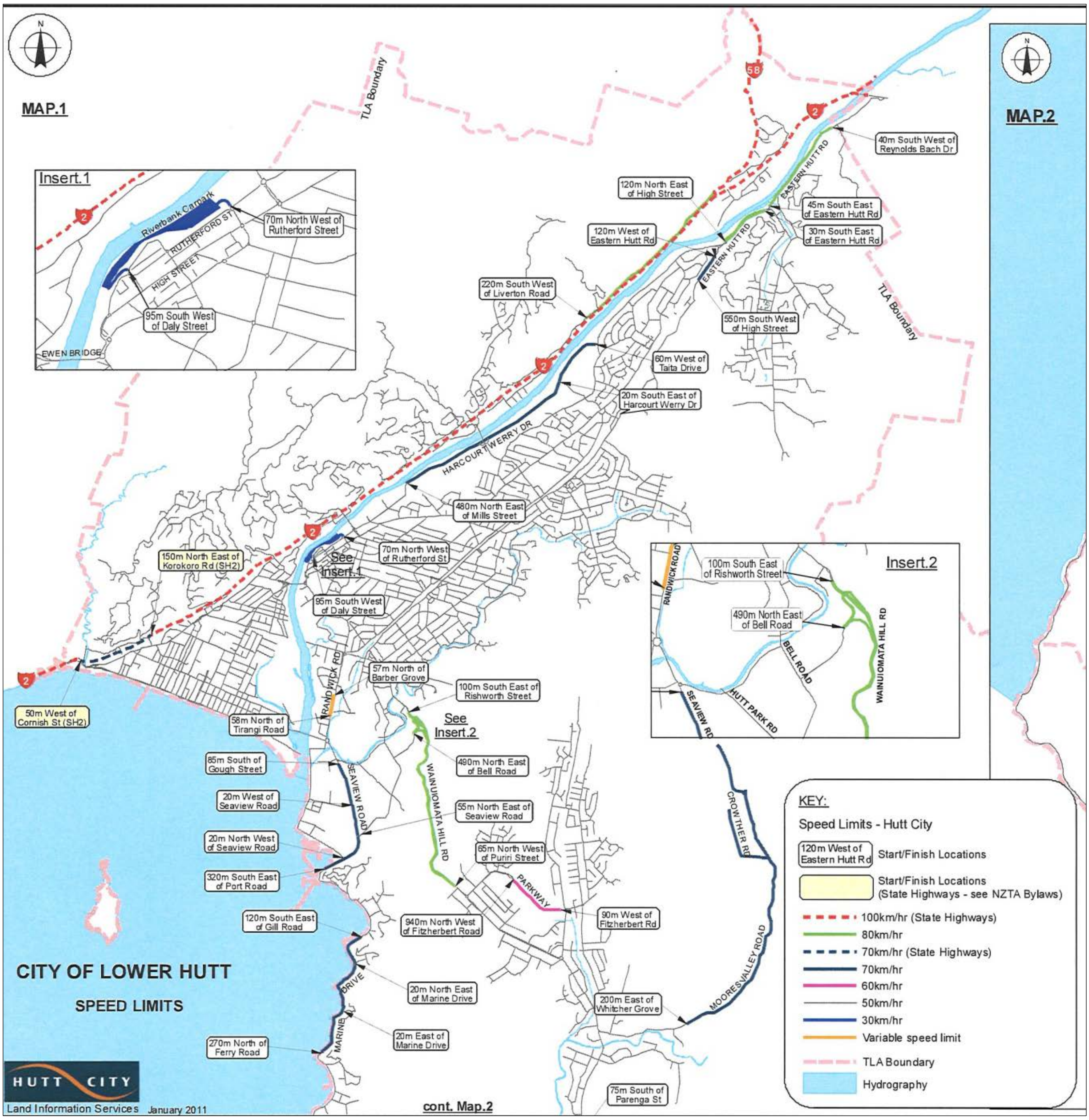


Figure 5.4 Map with no spatial descriptions (example from Nelson City Council)

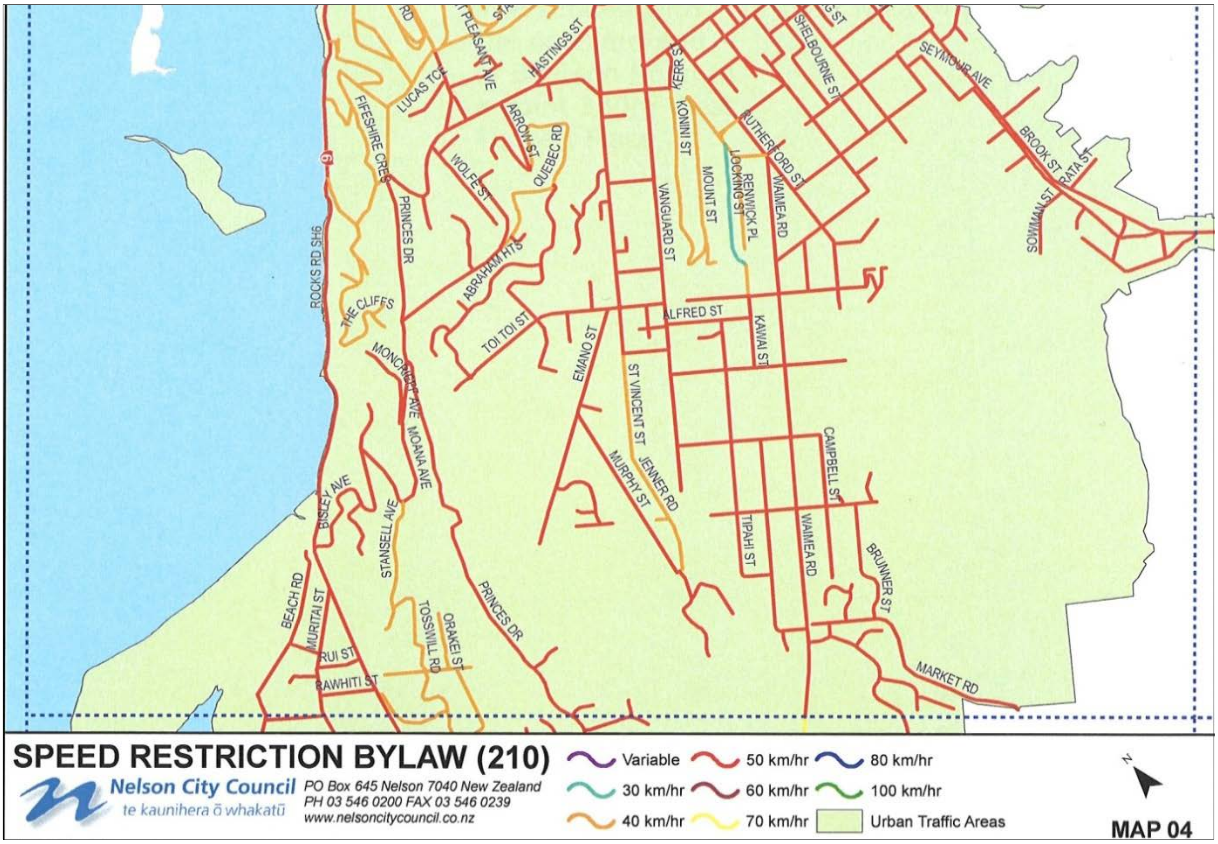


Figure 5.5 Table with spatial descriptions (example from Christchurch City Council)

Register Of Speed Limits

70 km/h Bylaw Speed Limits - Clause Seven

The roads or areas described in this register and as indicated on maps referenced to in this register are declared to be subject to a Speed limit of 70 km/h.

Description of 70 km/h Speed Limit	Date speed limit came into force	Legal Instrument
Barclays Road (Little River) from state Highway 75 to end	1 December 2005	Banks Peninsula District Council Speed Limit Bylaw November 2005 (Clause 5. Seventh Schedule)
Barters Road from State Highway 1 Main South Road north westerly generally for a distance of 50 metres.	*	NZ Gazette 29/1/2004 No 9 Pg 174
Bells Road (Takamatua) from Takamatua Valley Road to end	1 December 2005	Banks Peninsula District Council Speed Limit Bylaw November 2005 (Clause 5. Seventh Schedule)
Bridge Street from State Highway 74 to a point 50 metres measured westerly, generally, along Bridge Street from Kibblewhite Street.	*	NZ Gazette 29/1/2004 No 9 Pg 174
Breezes Road from State Highway 74 to a point 200 metres measured easterly, generally, along Breezes Road from Cuthberts Road.	*	NZ Gazette 29/1/2004 No 9 Pg 174

From this data, which was found on-line, it appears that RCAs tend to either publish spatially descriptive tables in conjunction with generic plans, or plans annotated with spatial descriptions. The spatial descriptions generally take the form of distances from intersections. However, this does not always provide an accurate location as it is unclear whether:

- distances are straight-line distances or running distances
- whether the measurements are taken from the left kerb, right kerb or centreline, which is a particular problem at acute-angle intersections
- uncertainty around location references that are made to ambiguous road boundaries (eg a distance measurement '100m north of Waterloo Quay' when the boundary between the end of Waterloo Quay and the start of Aotea Quay is not clearly defined).

Examples of where these issues have been identified in practice are outlined in appendix section A.3.

5.8 Testing the spatial accuracy of speed signs

As described in section 5.2, RCAs have an obligation to install speed limit signs no more than 20m from the point on the road where a speed limit changes.

A test of the spatial accuracy of a sample of speed limit signs within the speed limit register was undertaken to provide an indication of whether sign accuracy is an issue.

Due to the diverse range of methods for recording speed limits, a number of RCAs were sampled, using geo-referenced ortho-photography. While this approach relies on the positional accuracy of the photograph, it provides the opportunity to sample a larger number of signs than a field survey method would.

The following RCA's speed registers were tested, based on the aerial photography available and the quality of the speed register:[14]

- Auckland City Council
- Wellington City Council
- Hastings District Council
- Nelson District Council
- Tasman District Council.

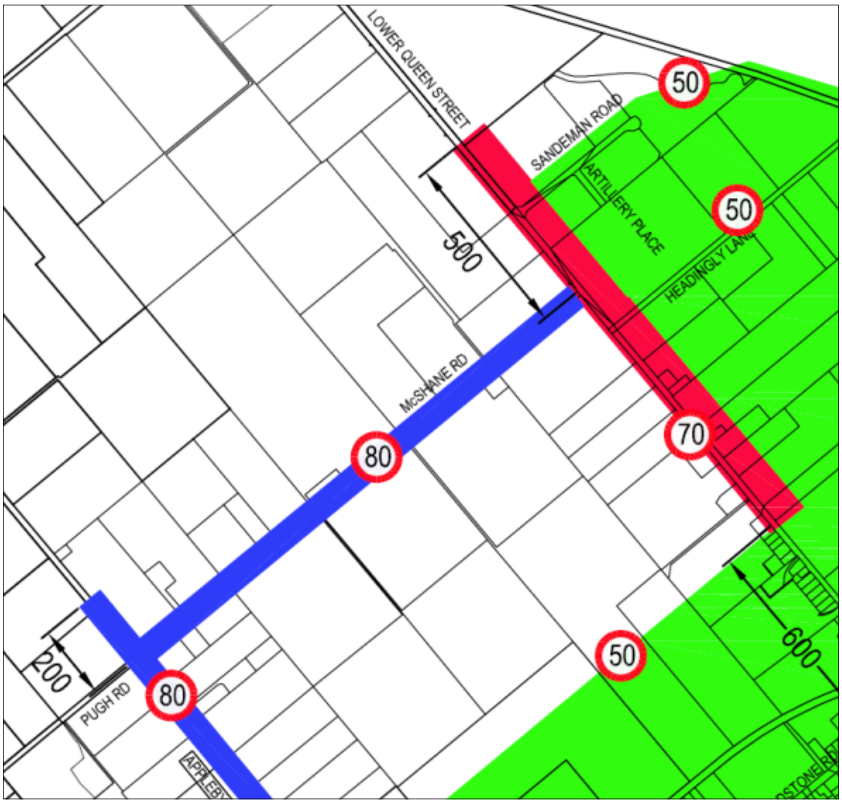
Example excerpts of speed registers and maps used in this desktop analysis can be seen in figures 5.6 and 5.7.

Figure 5.6 Nelson City Council speed limit register excerpt

Schedule G (70 km/h)		
Road Name	**Length**	**Authority by which the speed limit was set**
Aniseed Valley Road	Full length	Traffic (Nelson City) Notice No 1 1992 No 114 page 2526
Link Road	From the roundabout at the junction of Main Road Stoke and Salisbury Road to a point approximately 60 metres west of the said roundabout	Traffic (Nelson City) Notice 2000 No 59 page 1296
Whakatu Road Link	114m south of the Beatson Road roundabout to the Whakatu Drive / Annesbrook Drive roundabout	Traffic (Nelson City) Notice 2000 No 59 page 1296
Waimea Road	300m north of its intersection with the northern end of Beatson Road to a point 130m west of Tuckett Place	Traffic (Nelson City) Notice 1 1992 No 114 page 2526

[14] Dunedin City Council was not considered because it had no descriptions on where the speed limits were.

Figure 5.7 Tasman District Council speed limit map excerpt



The results of the comparison between speed limit register/map locations and speed limit sign locations are shown in table 5.2.

Table 5.2 Accuracy of speed limit signs

Council	No. of samples	No. sampled signs <20m from gazetted location	Average accuracy	Accuracy range	Estimated photograph accuracy	Comments
Auckland City Council (now part of Auckland Transport)	18	18	4m	1–17m	0.3m	Precise descriptions
Hastings District Council	5	2	82m	0–154m	0.3m	Ambiguity in descriptions due to reference points
Wellington City Council	16	14	11m	0–37m	0.3m	Ambiguity in descriptions due to reference points
Nelson City Council	5	4	19m	0–90m	0.5m	Ambiguity in descriptions due to reference points
Tasman District Council	7	3	37m	7–110m	0.5m	Ambiguity in descriptions due to reference points
Totals	**51**	**41**	**20m**	**0–154m**		

The results showed that of the 51 samples taken, 80% met the requirement in the Rule that a sign should be no more than 20m from the point on the road where the speed limit changes. However, there appeared to be a number of signs of concern, as the accuracy of the 51 signs sampled ranged from exact positioning (0m) to 154m.

It should be noted that some of the variation reported would be due to the difficulty in determining the gazetted speed limit location because of variations in the form of the published speed limit registers and the variation in the precision of the location descriptions.

During this study it was noted that speed limit signs were often attached to the nearest available power or light pole, and that speed limit signs were often not positioned opposite each other.

In general, those speed limit zones with more precise location descriptions tended to have more accurately positioned signs.

5.9 NZTA speed limit map workshop outcomes

This section details the outcomes of a workshop held with the NZTA on 21 November 2011 to present the findings of the initial tasks (above) and to discuss ideas on how the issues identified could be addressed in a national speed limit management system. The minutes from this meeting are provided in appendix section A.2.

Following a discussion of practice in Australia (refer to section 5.6), and New Zealand's inclusion in the Australian ISA Working Group, it was agreed that the NZTA should look to develop a speed limit mapping system separate from Australia's. This is consistent with the New Zealand Geospatial Strategy and the vision that:

> *... the NZ Transport Agency will lead New Zealand with a spatial Intelligent Transport System (ITS) for our national road network, empowering all customers to make better decisions by easily searching, viewing and accessing consistent, high quality information tailored to their individual requirements ...* (NZTA 2011).

5.9.1 Objective

During the workshop it was agreed that one of the main objectives of developing a national speed limit map should be to 'develop an electronic national speed limit management system that is an aid for Road Controlling Authorities, and makes the management of speed limits more straightforward'.

5.9.2 Benefits

The benefits of a national system for possible ISA implementation and general improvements in speed limit setting include:

- accurate, up-to-date speed limit information for the entire roading network
- the ability to undertake national analysis for consistency of speed limits
- a diverse range of users including ISA systems, in-car navigation devices and transportation engineers undertaking analysis
- time and cost savings through the elimination of the requirement for users to access multiple data sources (often not in map form) to gain a complete picture for an area
- a basis to easily share consistent information across the NZTA, other government departments/ agencies, RCAs, the commercial freight and public transport sectors, and other customers
- data that will accurately inform decisions, enabling ongoing improvements in safety, efficiency and cost effectiveness

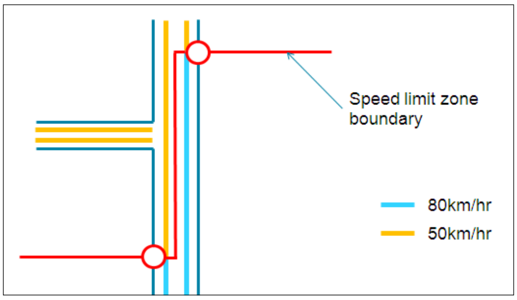
- efficiency in reducing the need for different organisations and commercial entities to collect speed limit information.

5.9.3 Electronic speed limit management – development considerations

Having agreed in principle that the development of a national electronic speed limit map or management system would be worthwhile, especially for the widespread implementation of ISA, there were a number of issues that should be taken into account. These included, but were not limited to, the following:

- School zones and other variable speed limits need to be taken into account; for example, the default speed could be reported and a flag included, indicating that it is a variable speed limit, with details including activation triggers (ie time of day, traffic incident, etc).
- Whether temporary speed limits should be included should be considered. This will be dependent on whether real-time accuracy can be achieved. Functionality for this could be incorporated, but not activated initially.
- Variations in speed limit between vehicle class and driver licence need to be considered. Possible solutions include creating different map layers to cover each scenario or, more simply, to enable ISA users to select options in a user-configurable ISA device. Whatever the solution, it should be flexible, as some users will regularly change status, eg whether towing a trailer.

Figure 5.8 Example of an offset speed limit



- Differing speed limits by direction need to be able to be accommodated, including instances where speed limits are offset.
- A means for accommodating elevated motorways, and other instances where roads may be multi-layered or 3-dimensional, needs to be incorporated.
- Information held should include the Gazette number, and ideally the Gazette notice should be stored as well.
- The system should be suitable for supporting advisory, supportive and mandatory ISA. There may be other uses that need to be considered, such as road user charges (RUCs).
- There should be a facility for map centreline updates, to ensure currency. This should ideally be an automated process.
- The system should be easy to use and flexible. This includes the ability to accommodate new technologies; eg there are a number of ISA applications available for use on ‘smartphones’.
- How data will be moved between the speed limit map and speed limit devices should be considered; eg at present, in-car navigation systems are often updated by the user purchasing an updated map. Other options include two-way cellular communications, eg via a SIM card installed in the device.

- Ease of use for RCAs, and the ability of RCAs to manage the data themselves, needs to be ensured, as it will be more difficult if RCAs are required to notify the NZTA of changes, particularly if they still maintain their own duplicate systems.
- A facility to provide feedback should be included, so that mistakes can be corrected.

5.9.4 Form

The two most obvious forms for a speed limit 'map' to take are GIS- or RAMM-based systems. The NZTA is already considering including speed limit as a carriageway attribute in RAMM. The benefits of RAMM are that all RCAs already use it and it has other information that is useful for analysis, including a link to the Crash Analysis System (CAS). This means that RCAs could manage the data for their area. One issue is that RCAs use different versions of RAMM, but if a user-defined table is used it should be possible to 'push through' an update to all RCAs.

GIS has the advantage of being more universal than RAMM, as it would be used by other map and navigation system providers. Using GIS would also allow maps and schedules to be generated by polygon, which would enable new roads to be easily accommodated.

Ultimately the best option may be to hold data in a form that can be easily converted or transferred between these two systems, with information from GIS fed into RAMM, or vice versa.

Consideration would need to be given to using a link-based or area-based data entry and recording system and the issues associated with each. It is likely that a link-based system would be required, but there may be options available to allow area-based data entry with automatic conversion to link-based data, particularly for any initial data entry.

In addition to the form of the system itself, consideration needs to be given to how information, including road centreline information, would be kept up to date. One option could be to use Open Street Map so that it can be edited by the public, triggering a notice to investigate, and if required update, centrally maintained information.

A further consideration relating to the form of the system is how updates would be undertaken. Ideally, RCAs would have access to any system, enabling them to make changes by directly accessing the NZTA system. This would still allow oversight by the NZTA, to ensure consistency between RCAs.

5.9.5 Transition

During the NZTA workshop it was agreed that the RCAs' data should be used in preference to any commercially held information. This was in part because commercial speed limit maps are understood to have been created by driving the network, and therefore may be of insufficient accuracy and may be out of date. Existing data sources from RCAs should be sufficient to develop a speed limit map to the same accuracy as existing RCA recording systems. However, the variability in existing GIS maps means that re-plotting with manual checking will most likely be required to achieve a high and consistent level of accuracy in the future.

In addition to sourcing speed limit information, the road centreline would need to be sourced for all of New Zealand.

Lastly, in any transition to a new system, it should be noted that by making a speed limit map publicly available, any inconsistencies in speed limit sign location and gazetted locations would become more obvious. It would therefore be in RCAs' interests to audit sign locations before the release of such a system.

5.9.6 Management and availability

During the NZTA workshop, views were put forward that the intention is that the NZTA would make speed limit data freely available, and for speed limit information to be publicly viewable. This would facilitate the introduction of ISA systems and also enable RCAs to simply provide a link to the speed limit map on their websites.

Another option was that speed limit data could be bought and maintained by another organisation.

5.10 Recommended changes to the land transport setting of speed limits Rule

The development of a national speed limit map has a number of benefits that will be realised regardless of whether or not an ISA system is deployed in the near future.

The development of a national speed limit map should be a priority, as speed limit changes are only going to become more prevalent in the near future, and early action will result in less work to transfer information to the new system.

Regardless of whether a national system is developed, there are a number of Rule changes that could be beneficial. These include:

1. specification of the accuracy required in delineating speed limit zones in the register/map, including guidance on how to measure the distance to the start/end points of speed limit zones
2. a requirement to record the GPS coordinates of the start/end points of speed limit zones (including accuracy requirements)
3. clarity over whether the location description or the GPS coordinates are the primary and secondary location descriptors
4. a requirement to audit or otherwise demonstrate that the speed limit sign location is within 20m of the gazetted speed limit zone – alternatively, audits could be incorporated into safety validations as part of network contracts
5. a requirement to audit the speed limit register/map to ensure that speed limit zones accurately reflect the gazetted locations.

If allowance for a national system is desired in the upcoming Rule changes, the following issues should be considered:

1. There could be a requirement for RCAs to use a GIS-based system for recording speed limit zones, including guidance on the format and accuracy required, so that data can be directly imported into the national system.
2. Given the organisation’s role, the NZTA could have the responsibility for developing a national electronic speed limit management system.
3. There could be a requirement for RCAs to keep their speed limit data up to date in any national speed limit management system that is developed.
4. Ultimately, the intention could be for RCAs to continue to manage their speed limits, and for the NZTA to store the data and make it available to others. To avoid duplication of data and effort, the requirement for RCAs to maintain a register of speed limits should allow this register to be held by the NZTA.

In developing any changes to the Rule it is important that care is taken not to increase the burden on RCAs.

Careful wording of Rule changes is required so that the status quo can remain, while including requirements that would enable a national system to function, when it is developed. In general, more specific guidance for RCAs on how speed limits should be recorded would ease the transition.

6 Global Navigation Satellite Systems (GNSS) coverage in New Zealand

6.1 Introduction

The universal feature of all ISA systems, irrespective of the typology, is the provision of in-vehicle speed limit information. However, the means by which the speed limit information is 'transferred' to the vehicle is not fixed.

In the first UK study of ISA, Carsten and Tate (1997) investigated a number of means for transferring speed [limit] information to vehicles. This included transponders fitted to speed limit signs, intelligent road studs, and autonomous ISA using speed limits coded to in-vehicle road maps on which the subject vehicle was located using in-vehicle GPS. Back in 1997, transponders were a well-established technology, whereas navigation systems and GPS were relatively new and, as a consequence, relatively expensive. While the resulting benefit–cost analysis favoured the lower-cost transponder-based architecture, the costs of such a system would fall on central government, whereas the costs associated with autonomous ISA could, in the main, be transferred to the user. GPS technology has since become a common and comparatively much cheaper technology. There are also emerging technologies, such as vehicle-based sign recognition, which will be widely used in the future.

Subsequent research and the increased availability of lower-cost navigation systems have seen preferences favour autonomous ISA using in-vehicle maps that may be locally broadcast via GPS positioning, which is now an everyday technology.

While there are significant advantages associated with autonomous ISA, the system relies on sufficient satellites to generate a reliable and accurate position. In Europe there is an abundance of satellites that are 'visible' to GPS receivers. However, in New Zealand the coverage is nowhere as extensive and the satellite geometry is not as good (at times the majority of satellites can be located on one horizon). Although coverage may be extended if the satellite navigation equipment is also capable of interrogating more than one satellite system, and/or contains dead-reckoning capability, such equipment is usually more expensive.

Unreliable GPS positioning may have a significant effect on accuracy and hence user perceptions of the value of ISA. For example, when a major road with a 100km/h speed limit intersects a local road with a 50km/h speed limit, drivers may be presented with incorrect speed limit information. This may not pose a major safety risk for users of an advisory ISA system, but could be a 'show stopper' or seriously impact on any planned implementation of other types of ISA.

The purpose of this section is to examine the coverage, reliability and accuracy of consumer-grade Global Navigation Satellite System (GNSS) receivers within New Zealand. It has been divided into the following areas:

- an introduction to GNSS
- a general discussion on GNSS and GNSS accuracy
- a desktop study on satellite availability within New Zealand
- a field study of GNSS accuracy
- the extent of GNSS coverage in New Zealand.

A summary of the findings are detailed below. For more detailed information refer to appendix B.

6.1.1 Global navigation satellite systems (GNSS)

Global Navigation Satellite System (GNSS) is the generic term for satellite navigation. Global Positioning System, more commonly known as GPS, is a satellite navigation system that is owned and operated by the US government. Other satellite navigation systems include GLONASS, owned by the Russian government; GALILEO, which is being built by the European Union and European Space Agency; and COMPASS, which is being built by the Chinese government. GPS is the current industry standard for GNSS systems.

There are a number of different grades of GPS receivers available, from survey-accurate GPS (centimetre positional accuracy), to mapping-grade GPS (sub-metre accuracy) and consumer- or recreational-grade GPS (with an accuracy >±3m). Recreational- or consumer-grade GPS devices are the most commonly used in in-car navigation.

GNSS works by using satellites that transmit weak signals to earth, which are picked up by the receiver's antenna. The antenna measures the time lag from when the signal was sent to when it arrives at the receiver. From this time lag, the distance between the satellite and the receiver can be calculated. Since the position of the satellites are known, the position of the receiver can be calculated – much the same way as you would with a compass and pencil, using intersecting circles. A minimum of three satellites is needed to calculate a two-dimensional position, and four satellites for a three-dimensional coordinate. The most commonly used system at present is GPS, and some higher-end receivers also use GLONASS to augment GPS (the European and Chinese systems are yet to become fully operative, expected in 2019 and 2015 respectively).

6.2 GPS accuracy

There are many factors that affect the accuracy of consumer-grade receivers, including the spread of satellites throughout the sky (satellite geometry), atmospheric conditions, obstructions such as buildings and hills, GNSS satellite signals that have bounced off another surface (multipath), errors in satellite position, and jamming, where the satellite signal is drowned out by another signal.

A quality-control setting commonly used on mapping or survey-grade receivers is 'elevation mask', where all satellite signals from below a certain altitude are omitted from position calculations. The rationale behind elevation mask is that signals from a low altitude are more likely to be multipath or affected by the atmosphere and obstructions such as buildings and trees. Some consumer-grade receivers have the ability to set the elevation mask.

Manufacturers' accuracy specifications are generally 15m or less (based on a sample of three GPS receivers). In an experiment using six consumer-grade GPS receivers, the average error (95% confidence level) ranged from 2.6 to 34.6m in open areas, 2.5 to 12.2m in young forest and 5.5 to 21.6m in closed canopy (Wing et al 2005).A similar study of four recreational-grade GPS receivers found that in open areas, the average error (95% confidence level) ranged from 3.5m to 6.7m beside buildings 7.7–65.6m high, and under tree canopy 20.1–25.2m high. An experiment by the Otago University School of Surveying (Denys 2010) on three handheld GPS receivers found that with 5–10 satellites, the accuracy was no better than ±7m at the 95% confidence level. However, as the experiment was carried out in a location clear of major obstacles (such as trees and buildings), the result should be interpreted as an optimal rather than a real-life result. This study also found that the receivers on occasions demonstrated errors of 20m for no apparent reason.

6.3 Satellite availability desktop study

As part of this research project, a desktop study was carried out to examine the effects of latitude and obstructions on satellite availability, and accuracy on standard GNSS systems.

The desktop study involved using Trimble Office Planning Software, together with the latest almanac (which lists the orbits of the satellite vehicles) to determine the maximum number of satellites available and the calculated DOP (PDOP and HDOP are measures of satellite geometry that act as an indicator of accuracy) for Auckland, Wellington and Dunedin, comparing:

1. using GPS satellites only; and using both GPS and GLONASS satellites
2. four horizons,[15] by setting elevation masks of 15°, 20°, 30° and 45°.

The results showed that GPS used together with GLONASS provided better coverage than GPS alone. The difference between GPS and GPS + GLONASS became more pronounced as the elevation mask increased, with similar results obtained for Auckland, Wellington and Dunedin.

The GNSS accuracy indicators (DOP values) were at an acceptable level (under 7), for all but the 45° elevation mask scenario.

Satellite availability varied considerably, with elevation mask ranging from 12 to 21satellites under a 0° mask to 3 to 5 satellites under a 45° elevation mask. The amount of time with three or fewer satellites in a 24-hour period increased substantially with a rising elevation mask. This varied from zero minutes at 0° and 15° elevation mask to as many as 1230 minutes for GPS in Dunedin at a 45° elevation mask. There were also significant differences between the GPS and GPS + GLONASS scenarios, with the latter having about 10 times fewer minutes with three or less satellites than GPS alone in the 45° elevation mask scenario.

A field study was carried out (measuring horizons from roads around the city) to determine a typical horizon in Wellington City, finding that a 10–15° horizon was realistic. This suggested that the elevation masks used in the desktop study were very conservative. However, there will be locations, particularly on central city roads, where high elevation masks or horizons are present, leading to reduced or poor GNSS coverage.

The desktop study could not model a number of variable and intermittent errors inherent in GNSS observations, such as multipath and atmospheric effects. Therefore a one-day field trial was undertaken.

6.4 Field study of GNSS accuracy

A one-day field trial using an in-car navigation GPS unit was undertaken in Wellington City, covering a route that provided a good mixture of ‘urban canyons’, tree cover, open areas, and areas with zero GPS availability (eg the Mt Victoria Tunnel). Two runs were made over the route, one in the morning and one in the afternoon. During the test times, between seven and nine satellites were present and DOP values were at an acceptable level.

The GPS data collected in the field trial was compared to Wellington City Council imagery (which has a horizontal accuracy of ±0.3m) to assess the GPS accuracy in comparison to the centreline of the driven lane.

[15] Fields of direct view to the satellites.

While analysing these results, it became apparent that the Garmin Nüvi 265 used in the field trial either 'pulled' the GPS position to the nearest mapped road (the mapped road being held in the GPS receiver) and/or used a form of dead reckoning, whereby the last fixes of position (and thus direction and velocity) were used to extrapolate the vehicle's position in a poor-coverage environment. Similarly, when the test vehicle was stationary, the recorded GPS points stayed in the same position rather than constantly changing from second to second as would be expected.[16] While no material published by Garmin could be found relating to this, it appears that many consumer-grade in-car navigation units apply a form of correction to the GPS tracking.

An analysis of the results using the raw GPS data file found that without any known form of correction, and adjusting for aerial photograph accuracy (estimated as 0.6m at one standard deviation) and taking account of the accuracy of the GPS and accuracy of 'true' position, the GPS was correct to within 5.1m, with a 95% confidence level (assuming accuracy was equal in all directions).

6.5 GNSS coverage nationwide

The extent of GNSS coverage on the road network is important so that speed limit changes and locations where there are advisory speeds are picked up. If there is significant signal drop-out, users will likely lose confidence in the system.

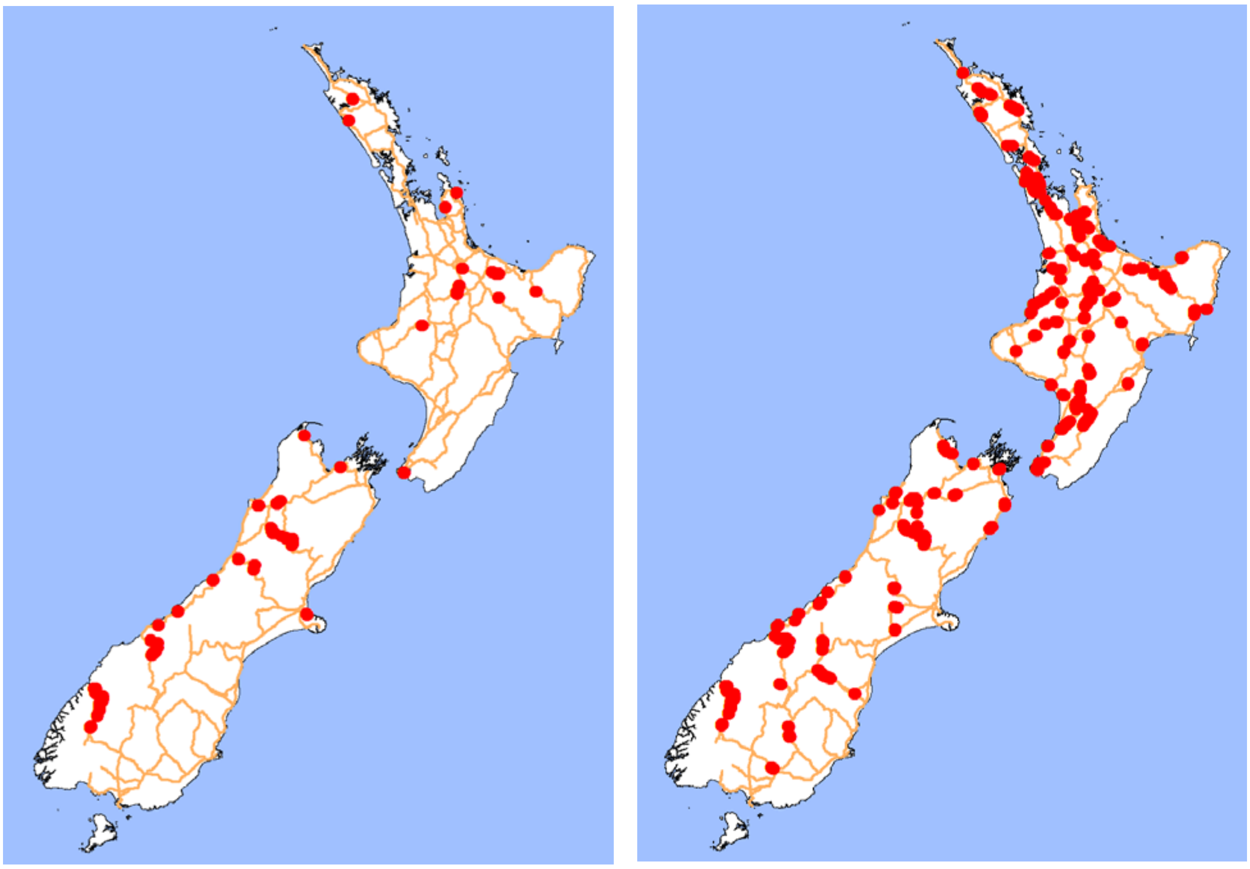
One readily available data source for providing an indication of nationwide coverage is the NZTA's High Speed Data Collection survey (HSDC), which uses GPS to position data points collected every 10m. Results from the 2009–10 and 2010–11 surveys showed greater than 95% GPS coverage over the state highway network. However, there was significant variability in coverage over these two surveys, with 99% coverage in the 2009–2010 survey and 96% coverage in the 2010–2011 survey (which is one of the lowest rates of coverage in memory – refer to appendix section B.6 for a plot of the 10m high-speed data points). Anecdotally, it is thought that sun spots significantly impacted the 2010–11 survey.

While these surveys indicated that that greater than 95% GPS coverage could be expected, it is the distance over which GPS coverage is lost that is important. Short sections without coverage are unlikely to have a material impact on the effectiveness of ISA, or user confidence in ISA; and even a small number of long sections of no coverage may be acceptable, as users can be alerted to where these locations are. However, frequent significant lengths of no coverage would have the potential to undermine the long-term uptake of ISA.

In order to identify locations where GPS coverage may be an issue, continuous sections with no GPS coverage for 500m or more were plotted, as shown in figure 6.1.

[16] When a GPS receiver is stationary and no corrections are applied, the plotted points will be scattered as the inaccuracy in the GPS position varies over time.

Figure 6.1 Locations with 500m+ of no GPS coverage for the NZTA's HSDC surveys, 2009–10 (left) and 2010–11 (right)

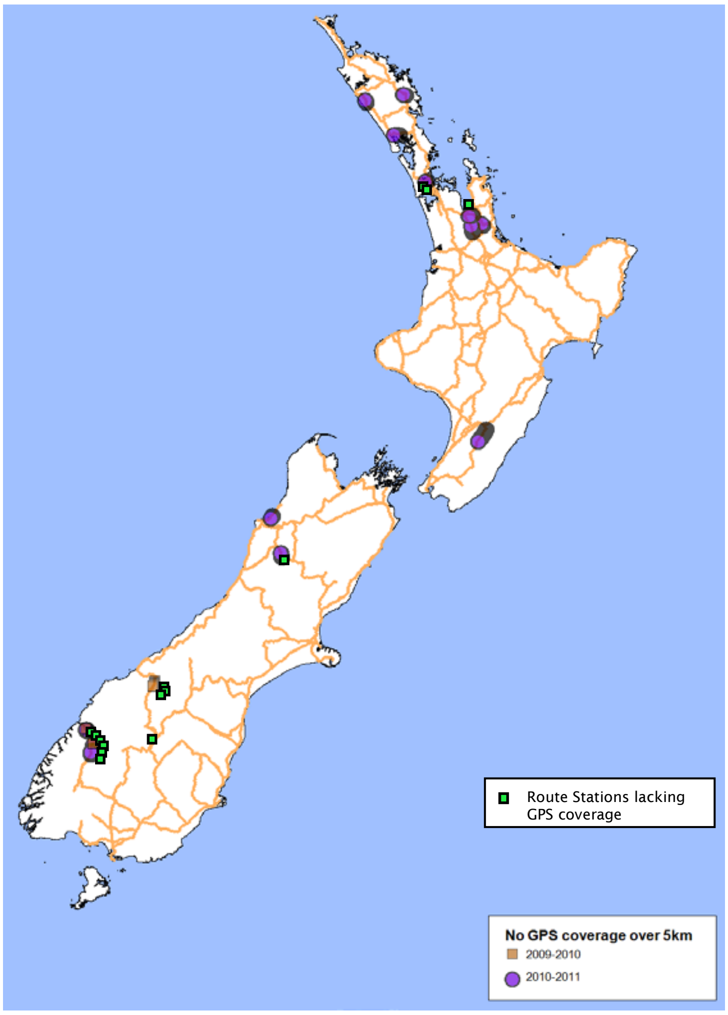


For the 2009–10 surveys, the locations lacking GPS coverage for 500m+ appear to be largely concentrated in relatively few areas, namely the main ranges and more mountainous terrain. However, the coverage for the 2010–11 survey is significantly worse, affecting most parts of the country, particularly the North Island (although this may be partly a reflection of the more concentrated state highway network).

In order to identify longer sections where lack of GPS coverage would render the ISA device unusable, 5km+ lengths were identified and plotted along with known locations of poor GPS coverage, as shown in figure 6.2.

There are a number of Route Stations known to consistently lack GPS coverage (shown in appendix B). For the 2010–11 HSDC survey, linear referencing was used on 11 Route Stations due to insufficient GPS coverage. These were located between Milford Sound and Te Anau, Haast and Wanaka, Reefton and Springs Junction, Thames and Coromandel, and on SH16 north-west of Auckland. Additional locations identified from the 5km+ sections included SH67 near Westport, SH2 between Woodville and Eketahuna, sections of SH27 and SH2 near Paeroa, SH18 near Albany, SH1N between Whangarei and Paihia, and SH12 between Oponini and Paparoa.

Figure 6.2 Locations with 5km+ of no GPS coverage in the HSDC surveys, and Route Stations lacking GPS coverage in the 2010–11 HSDC surveys



A summary of the distribution of continuous sections lacking coverage is shown in table 6.1.

Table 6.1 NZTA HSDC survey accuracy

Continuous length with no GPS coverage (m)	2009–10		2010–11	
	Number	Total length (km)	Number	Total length (km)
>0 to ≤100	246	10	564	21
>100 to ≤500	134	33	384	95
>500 to ≤1000	63	46	144	102
>1000 to ≤5000	57	112	203	422
>5000 to ≤10,000	3	24	17	115
>10,000	1	12	1	11
Total	**504**	**237**	**1313**	**767**
Total>500	124	194	365	650
Total>1000	61	148	221	548
Total>5000	4	35	18	126

While this analysis was limited to the state highway network, local roads could be expected to have similar percentages of cover.

As indicated in the preceding sections of this report, a loss of GNSS coverage is most likely to occur where there is a high horizon, in narrow, deep valleys, or in cities with tall buildings.

GNSS coverage in cities and towns will be very important, as this is where a large amount of travel occurs and where the majority of speed limit changes will occur. Coverage in remote rural areas will be more important if the ISA system adopted includes warnings for advisory curves. GNSS coverage will become more important as RCAs move towards setting speed limits appropriate to the environment.

This high-speed data showed that where there was GPS coverage, the accuracy of the GPS points was good, as shown in table 6.2. This level of accuracy appears to be sufficient for use in ISA, and is consistent with the findings of the desktop and field studies discussed in the preceding sections.

Table 6.2 NZTA HSDC survey accuracy

GPS accuracy (m)	2009–10	2010–11
Average	0.4	0.7
Minimum	0.1	0.1
Maximum	3.5	16.8

6.6 Navigation enhancements

6.6.1 GLONASS-capable devices

As discussed earlier, GLONASS is the Russian Global Navigation Satellite System, and devices that are capable of reading both the GLONASS and GPS systems will presumably achieve greater coverage than GPS devices in the years ahead.

A brief internet search of navigation equipment indicated that commercially available GLONASS+GPS-capable devices are increasing, with many of the major manufacturers producing GLONASS-capable equipment, including the Apple iPhone 4S. In addition, costs do not appear to be overly restrictive and may even be comparable to GPS devices. With the apparent increasing use of GLONASS, one could expect that in-car navigation devices will also increasingly adopt GLONASS capability.

Furthermore, a number of devices appear to have the ability to use multiple satellite systems such as GPS, GLONASS, GALILEO and others.

6.6.2 Integrated navigation systems

Integrated navigation systems augment GPS with 'inertial' or 'dead reckoning' navigation. An inertial navigation system uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation and velocity of a moving object, without the need for external references. Dead reckoning is the process of calculating current position by using a previously determined position, or fix, and advancing that position based on speed over elapsed time and direction.

In GPS navigation systems, inertial navigation is used to estimate the vehicle's position when the GPS signal is lost. However, as the period without GPS coverage increases, dead-reckoning errors accumulate and the estimated position becomes less accurate.

A brief internet search indicated that integrated navigation systems can be low cost. From the field trials conducted in this study, it appears that consumer-grade in-car GPS navigation systems may already use dead reckoning and/or a function where the GPS position is 'snapped' onto the nearest mapped road.[17] Unfortunately, detailed information on the systems used in in-car navigation units did not appear to be readily available on the internet at the time of this research.

6.6.3 Transponders

Autonomous ISA based on in-vehicle maps and GPS location has become the preferred option for ISA systems internationally. However, given the issues around GPS reliability and accuracy in some parts of New Zealand, a transponder-based system could have some advantages.

Such a system would involve installing a small device, or transponder, at all locations where communication with the in-car device is required. If this was done for every current speed limit change on the state highway network, it would equate to almost 900 transponders, based on the NZTA's register of speed limit Gazette notices. If advisory curve signs were also included, then significantly more transponders would be required.

When considering the total cost of such a system, a number of considerations would require further study, such as:

- whether transponders would be used only for sections known to have poor GPS coverage (while this would reduce material costs it may increase the administrative burden)
- the replacement rates expected
- whether transponders would be used for curve advisories, and how they would be installed; ie whether they could be attached to existing infrastructure at the start and end of each curve
- whether the ability to achieve 100% coverage through the use of transponders would outweigh the added cost and effort required to maintain such a system.

6.6.4 Other technologies

In addition to transponders and GNSS solutions, there are also other emerging technologies available, such as vehicle-based sign recognition, eg Mobileye™.[18] Vehicle-based sign recognition has the ability to detect and recognise speed limit signs, and potentially other signs such as speed advisory signs, pedestrian crossing signs, school zone signs, etc. These systems are increasingly being fitted to top-range vehicle models and could be a future alternative to map- and GPS-based systems. However, given the current cost of around $2000 (installed), these have not been considered a viable alternative at this time.

6.6.5 Cellular network coverage

Many ISA systems have the capability to update the speed limit map used by the unit via a SIM card over the cellular network. If users wish to use this capability, broad cellular network coverage is required.

Cellular network coverage in New Zealand is limited in places, but the main network providers claim to cover around 97–99% of the places that New Zealander's live and work.[19] This means that the majority of users will be within range of the cellular network to receive system updates, and it is likely that the

[17] Where the GPS points recorded by the GPS unit are pulled or snapped onto the road centreline.

[18] www.mobileye.com

[19] As reported on the websites of the main cellular network providers in New Zealand.

remaining 1–3% will come within range frequently enough that cellular network coverage should not be an issue in the use of ISA equipment.

6.7 Comment

If specific in-vehicle ISA equipment was used, the cost of the equipment would be borne by the user, with standard units ranging from about $100 to $650, and as such it would seem sensible to provide a range of options to users for devices that include ISA functionality, such as:

- GPS
- GLONASS + GPS
- integrated navigation systems

Increasing cost

Increasing reliability/accuracy

The main consideration would be whether to augment the coverage provided by the user equipment with infrastructure, such as transponders, to improve the reliability of the system. This could either be a full transponder system, or involve the use of transponders in locations where GPS coverage is known to be poor, and recording of such locations could be included in any national speed limit mapping system that was developed. Such a system would significantly increase the management and cost burden.

An equipment-based solution would enable users to choose the equipment that best meets their needs, with more expensive inertial navigation and GLONASS-capable units available to those who desire better coverage.

6.8 Summary and conclusions

Most consumer-grade GNSS units exclusively use GPS satellites. Positions derived from GNSS are prone to varying types of error sources, and are particularly affected by terrain and tall buildings and other obstacles that increase the horizon. There is little difference in the number of satellites available over the different latitudes within New Zealand. However, there are significant periods where the number of satellites decreases dramatically with a rising horizon. Having undertaken a desktop study and field test, an overall accuracy of 'within 15m' in most situations would appear to be a realistic estimate of in-car navigation consumer-grade GPS.

Assuming an average refresh rate for GPS receivers of 1 second, table 6.3 shows the possible errors in position for a vehicle entering a new speed zone.

Table 6.3 GPS combined error for different speed zones

Speed(km/h)	Estimated GPS accuracy(m)	Distance travelled in 1sec (m)	Combined error (m)
30	15	8	23
50	15	14	29
70	15	19	34
100	15	28	43

Given that the combined error from a GPS receiver with a 1sec refresh rate together with GPS accuracy at a speed of 100km/h is 43m, speed limit change and advisory warnings should be triggered well in advance of the change to give users time to react and to 'absorb' the combined error in the system.[20]

An initial analysis of GPS coverage indicates that the ISA system is likely to be unreliable, or even unusable, in about 12 locations (over Route Stations of around 10km in length), with the potential to drop out for shorter lengths (of around 500m) over much of the country, although, this does appear to vary from year to year.

Consumer-grade GPS devices are the preferred option in terms of cost and ease of use, and provide a greater range of equipment options. Given the current technology in in-car navigation devices together with the increasing use of GLONASS-capable systems, as well as 'filtering' mechanisms such as 'snapping' the GPS position onto the road centreline, as well as the possible inclusion of dead reckoning, it would seem reasonable to roll out an ISA system based primarily on a consumer-grade in-car navigation system. Consideration could be given to installing transponders in locations where GPS coverage is known to be particularly poor. A mixed GPS-transponder system could also extend the system to cover roadworks and other sites. An alternative and emerging option to transponders is vehicle-based recognition of speed limit signs.

Further research that could be undertaken to build on this study includes:

- testing the device's directional accuracy in a moving vehicle
- testing the effect of elevation on the device's positional accuracy with only three satellites
- investigating the 'filters' used by different manufacturers for in-car navigation units
- repeating the field tests over multiple days with different GPS brands, to build up a statistically viable database for analysis
- undertaking field tests in locations known to have particularly poor GPS coverage
- collecting data on GPS signal drop-out from in-car navigation units as they are used by willing participants.

[20] Assuming that 1Hz is the longest cycle time used by ISA systems.

7 Focus groups on the user acceptability of advisory ISA

7.1 Introduction

The aim of this focus group work was to better understand the views of potential users of advisory ISA technology, to identify those groups that could be supportive (either personally or for use by others), the issues that concerned potential supporters of ISA, and the potential impacts of various incentives that could increase uptake of ISA.

7.1.1 Focus group method

Four focus groups were conducted, each with representatives from a different driving population:

- drivers over 65 years of age (referred to here as 'older drivers')
- drivers under 25 years of age (referred to here as 'young drivers')
- drivers of fleet or company vehicles (eg truck drivers and tradespeople, referred to here as 'fleet drivers')
- drivers outside these groups (eg non-fleet drivers between 25 and 64 years of age, referred to here as the 'general sample').

The majority of participants were recruited through an email distributed to local members of the New Zealand Automobile Association (AA), with numbers in some groups supplemented through a sample of contacts previously unknown to the facilitator (eg referred through colleagues). Material sent to participants prior to the focus group sessions gave a general overview of ISA technology and outlined the focus groups as a discussion of the implementation of a new GPS-based speed feedback system. Each participant received a $30 MTA voucher and food was provided.

The focus group sessions were conducted by an experienced moderator whose role was to facilitate participation by all members. Best-practice techniques were used to structure the focus group sessions carefully, selecting simple and understandable questions, optimally sequencing these questions, and providing a physical environment that encouraged the participation of members. Pre-screening of participants ensured there were no prior acquaintances in the group. Audio-visual stimuli were used to present the ISA technology and elements of the HMI design for discussion.

7.1.2 Focus group analysis

A content analysis of the transcripts from the four focus group recordings was performed using NVivo qualitative analysis software. To provide a measure of the strength of messages from the groups, a count of the number of references[21] made is included where the groups varied substantially. The key findings of these focus groups are reported and summarised in section 7.10.

[21] A 'reference' refers to each mention of a particular theme or subject by a focus group participant.

7.2 General attitudes towards the technology

The majority of references made regarding first opinions of ISA technology were positive, although there were also some negative opinions expressed. These are briefly summarised in this section. Specific opinions regarding features of the device are outlined in the following sections.

7.2.1 Positive attitudes

The older drivers saw significantly more benefits from the technology than the other groups, with 19 positive references made. They generally believed that they were a law-abiding section of the population but would appreciate the assistance of an ISA device. The majority indicated they would purchase an ISA device if it was available on the market and at an affordable price. The fleet drivers were also generally positive, particularly those who already had GPS monitoring equipment in their vehicles (eg truck drivers). This group, in particular, focused on the positive addition of the advisory feedback, as this was not currently monitored. Young drivers were less interested in having the technology themselves, but did suggest that there would be a market for it, particularly for older drivers or for parents with children learning to drive. The general sample group was generally not supportive; however, this group did agree that driving in urban environments is becoming more difficult with changes to speed zones, so this would be one situation where a device could be useful (although they believed that noticing these speed changes was the driver's responsibility).

7.2.2 Negative attitudes

There was initially some belief within the older driver group that the device would be too controlling, when drivers should be able to follow speed limits themselves.

> *'It's another nanny state thing.'*

This opinion changed for most as the discussion developed. Overall, the young drivers indicated they would not consider buying one for themselves without an incentive (see 'Insurance discounts' in section 7.10.1 for further detail). The general sample group had stronger opinions, suggesting that they hated the idea. The fleet drivers were generally supportive, but did suggest a wider preference of investment in road design improvements, so roads are self-explaining. However this was outside the scope of this research project.

7.3 Compliance with the technology

The issue of whether drivers would comply with the device warnings was most commonly raised by the young drivers (17 references), followed by the general sample group (10 references) and the fleet drivers (8 references). The older drivers raised no real concerns about compliance; they considered themselves law-abiding so did not see this as an issue for those in their demographic.

The young drivers suggested that they would probably ignore the warnings of the device if they wanted to speed, while the general sample group believed that compliance with the speed limits was the responsibility of the driver. The general sample group felt they were capable of following the signs on the road themselves, so did not believe the device would be of much assistance.

The fleet drivers had fewer opinions on the compliance aspect, as they felt they were regulated to a higher degree in their driving behaviour than private driver groups. Therefore ignoring the feedback from the device would be less of an option for this group.

While the young drivers did not generally believe people in their demographic would comply with the device, they did believe others would, particularly the elderly (and the older drivers' reactions to the technology supported this view).

7.3.1 Lack of freedom

The key issue raised by drivers was the belief that the technology took away the driver's freedom and there would be a perception of 'big brother' or too much control by the government (eg 'nanny state'), to which people would be opposed. These concerns around freedom were of particular concern to the young drivers and general sample group (and particularly within the context of the variable ISA, as the speeds presented are advisory rather than a legal requirement). The majority of older drivers and fleet drivers were not as concerned about this; perhaps for the latter as their driving is highly regulated anyway, and for the older drivers because of their perceived high level of pre-existing compliance.

7.4 Concerns around the technology

7.4.1 Annoyance

Concerns were raised about the potential for the device to cause too much annoyance to drivers, resulting in the possibility that drivers would either tamper with the device or not want it installed. This was particularly true for the young drivers, with 11 references made to the device being annoying (compared with two references each for the fleet drivers and general sample group, and zero references for the older drivers). However, the young drivers also believed that the fact that the audio was annoying would make it more effective and they would be more likely to comply with it. Particular concerns were raised around the interruption to music, or the device 'crying wolf' (eg indicating school zone speeds during weekends). Overall, most groups suggested that the level of annoyance could be reduced through the specific design of the Human–Machine Interface (HMI) feedback (see section 7.7 for further information).

7.4.2 Technophobia

Contrary to expectations, the older drivers did not have any concerns about the technology itself in regards to it being too complicated. Only one reference was made to this by the general sample group, who suggested some people may be overwhelmed by the technology.

> *'A lot of people I think are intimidated by the technology as well, and if things start flashing at them telling them you need to download updates, or even just flashing when you're going around corners and stuff, they get sort of all flummoxed.'*

7.4.3 Distraction

Driver distraction was of most concern to the older drivers, with 10 references made, compared with five for the general sample group and three each for the other two groups. The older drivers suggested that they would be concerned about diverting their attention from the road and adding another item to their dashboard. However, this group also said for this reason they would generally focus more on the sounds, which they felt were less distracting than the visual display.

The general sample group felt that the device would be distracting at first but not over time for themselves personally, although they expressed concern that some groups may become more distracted (eg those who can't switch off from technology, such as young people). The fleet drivers generally considered that because there are already plenty of distractions for drivers with GPS and radar detectors, the ISA device wouldn't be a great concern (with the exception of the truck driver in this group). The young drivers suggested that while the device could be a distraction, it would be no more so than other devices already present, such as cell phones.

7.4.4 Negative effects on driving

The general sample group had the strongest feelings that the ISA devices would have a negative effect on people's driving, mostly as they believed it was 'spoon feeding', making drivers less alert to their surroundings. Overall, this group made 19 references to the negative effects the device could have on driving.

The young drivers made seven references to potential negative effects, mostly focused on changing between vehicles with the technology and those without. They believed that some people would have difficulty with this; however they thought that they themselves would be able to adjust. One participant suggested that some motorists would possibly try to challenge the device, pushing their speed to what they could get away with. The fleet drivers also suggested that it could have a negative effect when driving in a vehicle without the device if the driver had become accustomed to the feedback; however they believed they were well-trained enough (through defensive-driving courses) not to rely on the information. Overall, the older drivers saw mostly benefits to their driving (see below) but suggested it could be difficult for some people, particularly young people with less driving experience, to change to a vehicle without it.

7.4.5 Positive changes in driving style

Overall, the older drivers saw the most benefits in the technology for improving their driving, with eight references made to this. This group believed they would still pay just as much attention to the road, but would be reassured by having the device there in case they missed something. One participant also saw it as an opportunity to compare their performance to the device.

The young drivers suggested that the device would make them more aware of the speed limit, but this may not necessarily mean they would then comply with it. However, this group suggested that it could be helpful when learning to drive, claiming that the physical operation of the car is difficult to learn, so one less thing to attend to would be beneficial. This group suggested they would consider themselves overconfident drivers, so were perhaps not as likely to see benefits to their driving from the device, but that less confident drivers might, as it would simplify the driving task (eg when learning to drive).

> *'Because the hardest part about learning to drive is actually using the car. If you don't have to focus on anything else, then you'll be able to ... change gears and steer better.'*

As stated in the last section, the general sample group saw the device as having a negative effect overall on driving. This group suggested that there could be some improvement for bad drivers, but that this would be outweighed by the negative effect on other drivers' behaviour. The fleet drivers generally did not think that ISA would impact on their driving as they generally considered themselves to be good drivers and that they would not rely on the feedback anyway.

7.4.6 Reliability of the feedback

One of the other perceived barriers to ISA technology identified in previous studies relates to concerns over the reliability of the technology itself. The older drivers suggested they themselves would treat the device as a fall back, rather than as replacing their attention to speed signs, meaning they would not be too concerned over reliability; however they also trusted that the technology would be reliable.

> *'Most modern electronic equipment, they're so reliable, they're just ridiculous in detail.'*

For both the general sample group and young drivers, concerns were raised that the information in the database would have to be kept current. For the young drivers, this concern was based on issues they had previously had with GPS data. However, this group also believed that if the product was for sale, it would be at a standard they would be happy to trust.

The general sample group raised concerns about who would be responsible for the data updates – eg local or regional councils, or national bodies. They also believed that there should be compulsory updates, or possibly checks during warrant of fitness renewal that the data being used by each device was up to date. The fleet drivers raised no concerns around the reliability of the data, but had more general concerns about the way advisory limits are set, indicating a potential reluctance to trust advisory feedback generally.

7.5 Incentives

The focus groups examined the potential use of incentives to encourage uptake of ISA technology. The most popular, and arguably the easiest, system to implement that was discussed was insurance premium discounts, but other incentives were also presented.

7.5.1 Insurance discounts

Discounts to insurance premiums were of most interest to all private car driver groups (older, young and general sample groups), particularly those in the young and older driver groups. As mentioned earlier, those in the young driver group were not generally interested in the technology in the absence of incentives, but became more interested when it was associated with insurance discounts (11 references were made). This group suggested this would be the best incentive for people in their demographic, due to the high premiums and excesses imposed on their insurance. Overall they were more in favour of a discount on their excess than on their premiums, but both options were supported. Those in the older driver group were also supportive of the use of incentives but were not as concerned with what type of incentive. Those in the general sample group were more sceptical about whether the insurance industry would be interested in offering discounts.

7.5.2 Other financial incentives

The other financial incentive considered by the groups was a reduction on the cost of registration. The young drivers suggested this could be fairer, as everyone has to register their car, while not everyone gets insurance (as it is not compulsory in New Zealand to have any vehicle insurance). However they acknowledged that there was no link between registration and speeding risk. The general sample group suggested that any kind of financial incentive would have to be significant to offset the cost of buying something they were not that interested in having.

The fleet drivers stated that in the past they had had financial bonuses for good driving and that this could be an incentive for compliance. However, their main interest was in increasing the safety culture of their workplace, rather than anything financial.

7.5.3 Speeding fine avoidance

While not directly an incentive, one of the key motivations for the participants for fitting a device would be to avoid speeding fines. This was of particular interest to both the older and young driver groups (the older drivers mostly out of embarrassment, as well as the financial cost). The general sample group suggested that if the device could give feedback on the level of fine risked by the driver’s behaviour, this would possibly be an incentive to have the device.

7.5.4 Use of ISA as punishment

None of the groups were in favour of the devices being used as punishment (eg demerits or decreasing rewards for non-compliance), preferring a focus on a reward schedule for compliance, rather than a negative-stimulus schedule for exceeding speed limits. Any fine systems were considered to be too hard to administer, with those in the older driver group in particular suggesting that people don't pay their fines as it is, so it would have little effect.

7.6 Introduction of the technology in the New Zealand context

The groups were asked about their preferences on how the technology could be introduced in terms of the various driver groups, or areas where it could be implemented first.

7.6.1 Compulsory groups

The groups were asked if there were any segments of the community for whom they felt the technology could be made compulsory. The older drivers had the strongest opinions on compulsory introduction, with 12 references. They suggested that young drivers (under 25) or those learning to drive may benefit from compulsory ISA technology, although they were concerned about the cost for people who could not afford to purchase the devices. Surprisingly, there was some support from this group for making them compulsory in the vehicles of drivers over 75 year old, despite the majority of the group being over 75 themselves. There was also some support from this group for fitting the devices to the vehicles of people who had multiple convictions, but only if the devices were not able to be turned off, as they did not believe they would have an effect as an optional device.

The young drivers suggested that making them compulsory for repeat speed offenders could be beneficial; however, they also agreed this may not have the desired effect (ie may not stop this group from regularly speeding). They also suggested though that if they were to be introduced to the general population after having been used in this way, there could be a negative perception of the devices.

> *'You get this if you're bad. So it's like if you have to drive with this then you're a bad driver.'*

The general sample group agreed that making the devices compulsory would also increase resistance to them, but suggested that there could be some benefit for learner drivers, while the fleet drivers did not believe compulsory introduction would be effective for repeat offenders, particularly if it was just advisory. The general sample group was also concerned about the costs involved, particularly of updates.

> *'You might again end up with two classes – those that can afford these tools to keep them honest and those that can't – and again, you're kind of making that divide worse because people can't afford these tools and they're then gonna get [a] fine [and] they're gonna get poorer ...'*

7.6.2 Target groups

When asked for which groups the devices could be the most effective and beneficial, the young drivers had the most suggestions (16 references) followed by the older drivers (10 references). The young drivers focused predominantly on professional drivers, particularly taxi drivers, but also suggested some benefits for those learning or on restricted licences. This group also suggested it would also be very beneficial in rental vehicles for tourists. The older drivers also suggested young and older drivers as target groups, even if they were not compulsory. The general sample group generally saw the best use of the device as a training tool for young drivers, as long as they didn't become reliant on it.

> *'… the more we can give learner drivers and young drivers, the safer everyone's gonna be down the track. And so I think a lot of the stuff might have the greatest benefit for the new drivers and wean them off it so they don't become completely reliant on being spoon-fed it all the time. It might be the best compromise.'*

The fleet drivers saw benefits for their own group and would be interested in establishing it on a trial basis. They suggested that those who drive more varied routes would see the most benefits, rather than those who follow the same route repeatedly, as many of the truck drivers do.

7.6.3 Geographic targeting

The groups as a whole did not have strong opinions on how the technology could be rolled out geographically. There were suggestions made by both the young drivers and the fleet drivers that the open road and state highway environment would be of interest for variable ISA, as there are very few curves with speed advisory signs in urban areas. However it was noted that the speed limits vary far less on state highways. Generally, the feedback did not favour one geographic approach over another.

7.6.4 Initial tolerance

The groups were asked whether if the technology was to be introduced, there should be an extra tolerance given in the feedback (eg the thresholds at which the feedback for non-compliance could be gradually lowered as the driver gets more comfortable with the device). The fleet drivers were supportive of no leeway, although the young drivers suggested the tolerance level should be set at the standard used by the police when issuing tickets.

7.7 Human–Machine Interface (HMI) design

The groups were presented with mock-ups of how the feedback could be presented on the screen (refer to appendix C for details of the visual mock-ups provided) and the accompanying sounds to be trialled in the next phase of the study. For ease of presentation, participant suggestions for speed limit feedback and advisory feedback have been separated here.

7.7.1 Audio feedback – speed limits

The older drivers had the most suggestions for the design of the audio feedback, with 37 references made. This group was generally more in favour of audio than visual feedback, as it does not involve the driver taking their eyes off the road. The specific feedback from this group on how the audio should sound was that it should be:

- distinctive (different from backing signals and other vehicle sounds)
- midrange (not too high- or low-pitched, as people can lose these ranges in their hearing)
- verbal
- a noise, rather than something more musical.

The bulk of the feedback from the young drivers related to the volume of the audio and whether the sounds selected were strong and distinctive enough to be heard over vehicle and stereo noise. This group suggested that connecting the device to the stereo, to have the sounds interrupt the music, would be of assistance. The fleet drivers were also concerned about this, as most of the vehicles they use have significant cabin noise.

The other questions asked about the audio feedback for the speed limit advisories and the sounds for non-compliance. The latter included preferences regarding the number of times the sound should repeat, and at what speed and timing they should trigger and cease. The older drivers were supportive of the 3km/h and 8km/h thresholds suggested, but there was debate in this group about how many times the warnings should repeat until the driver slowed the vehicle. For compliance, it was suggested that continuous feedback would be beneficial, but this would create more annoyance and therefore led to greater resistance to installing the device. This was a view shared by the young drivers. The general sample group believed the warnings should stop after a set period of time, as it is the driver's responsibility to decide whether or not to comply.

7.7.2 Visual feedback – speed limits

The older drivers expressed the most opinions on the visual display, with 21 references; the bulk of these related to the way the speed advisories were presented (see section 7.7.4). This group was largely happy with the proposed presentation of the speed limit feedback, as it corresponded with the signs they were accustomed to seeing on the road. The young drivers largely supported this view. However, they were more supportive of the visual flashing when the speed limit was exceeded, rather than the display changing colour – they felt this would be more effective at drawing one's attention and could compensate in situations where the audio feedback was missed.

The older drivers were also concerned about the amount of light from the screen, suggesting there should be an inbuilt ambient sensor that automatically adjusts brightness levels in reaction to the light level outside the vehicle. This was a concern shared by the fleet drivers, but was not raised in any other discussion.

7.7.3 Audio feedback – speed advisories

Two different sounds to accompany the advisory speed visuals were presented, one to the first three groups, the other to the last group. The first sound presented to the groups for the advisory speed warning was generally unpopular, particularly with the older drivers, who felt it was not strong enough to be differentiated from other vehicle noises. The second sound was more popular than the first, but was still not considered ideal in terms of ability to distinguish it from other noises.

The only group that was supportive of warning sounds for going over the advisory speed limits was the fleet driver group. All other groups believed that there should only be feedback on the speed limits rather than on the advisory speed signs (as is being considered in this research).

7.7.4 Visual feedback – speed advisories

The older drivers did not like the way the advisories were presented with a yellow border, preferring a presentation of the signs as they currently appear on the road (yellow background with black border). There was some debate within this group as to whether the type of advisory (eg corner or crossing signs) should be presented in conjunction with the new speed. This group also suggested that keeping the speed limit roundel on the screen was too much information and that only the advisory sign should be presented.

The young drivers also suggested that the yellow border presentation was not clear enough and they would prefer the standard advisory sign. In contrast to the older drivers, this group was in favour of the presentation of the advisory sign to the right of the speed roundel as presented in the mock-ups. In line with the other groups, the fleet drivers were also in favour of the visual presentation reflecting the actual signs in the road environment. The general sample group agreed with this, but suggested that only the speed of the advisory should be shown, not the type of hazard.

7.7.5 Customisable

The other very strong feedback from all of the groups was that the ISA device would be more acceptable to the highest number of people if it was fully customisable to their preferences, similar to the way GPS devices currently allow customisation of narration voice and sounds. This customisation was generally focused on audio feedback. Two of the groups (young drivers and fleet drivers) also suggested that the background screen colour could be customised to the driver's preferences, similar to backlit stereo screens.

7.8 Design suggestions

In addition to the details of how the information was presented, the groups were also asked for general suggestions on how they would like the device to work, including additional features that could be integrated.

7.8.1 Amount of warning

A range of suggestions were made regarding when the speed limit change warning should be triggered relative to the speed zone boundary. The older drivers suggested they would prefer to be warned about the change at a distance that would allow for safe deceleration; this would therefore vary according to the amount of speed change required (eg a longer distance for 100km/h down to 50km/h than for 100km/h down to 70km/h). The general sample group favoured some kind of voice warning, similar to GPS feedback, of the distance to the next speed zone. The young drivers were more varied in their feedback; some participants favoured feedback at the speed zone boundary (no warning), while others suggested that the same amount of warning the driver would get from the sign (eg the point at which they could see the speed limit sign) would be optimal, and others suggested distances of between 400m and 1km.

7.8.2 Difference from GPS

Both the young driver and general sample groups (five references each) did not see the benefit of having an ISA device that only gave speed-related information, compared with other devices (eg current GPS devices) that currently do some of this while also providing other information. These groups suggested that if ISA was introduced, it should be integrated with standard GPS functions such as provision of driving directions.

7.8.3 Additional features

The groups were asked about their interest in other additional feedback that could be provided by the ISA devices, including information on fuel consumption, vehicle emissions, passenger ride comfort and anything else that would improve its attractiveness.

The young drivers saw little incentive in having fuel consumption information displayed, believing that people interested in this would already have cars with built-in monitoring systems (eg hybrid or other modern vehicles). They also believed that the relative expense of measuring passenger ride comfort would outweigh the benefit. While they personally did not want the technology, this group suggested that lane positioning could be useful for some people. The older drivers were not particularly concerned with fuel consumption being included in the device; most suggested modern vehicles already provide this information. The general sample group suggested that fuel consumption could be of interest for a short period but was a novelty. This group also was not interested in passenger ride comfort.

While not specifically a feature proposed or asked about in the focus group sessions, all the groups discussed whether having real-time information would make the technology more attractive. The addition of updates about temporary speed zones, roadwork sites, school buses and accident sites was very popular. The older drivers also suggested the addition of feedback on when there are cyclists present on the road ahead, and changes to the feedback to account for weather conditions.

7.8.4 Design of the ISA unit

The older drivers suggested they would be more supportive of having the device in their vehicle if it was possible to move it between vehicles or remove it when the vehicle was not in use. Ideally, over time they felt it would be best if it was fitted as a part of new vehicles, rather than being a separate piece of equipment; one reason given for this was concern over potential theft.

The young drivers were also supportive of the technology being built into existing equipment in the vehicle rather than being a separate device; as mentioned earlier, this group suggested incorporating it into the stereo system:

> *'Maybe it would be good built into a car, like in the stereo system or something. Every time you hit a speed sign it would go off the radio and that would pop up and then it would just go away and then just the radio would come back on or whatever.'*

The other groups had fewer opinions on the design of the particular unit; however, the truck drivers within the fleet driver group were not generally keen on adding an additional screen to their environment.

7.8.5 Optional use

Participants were asked whether giving the device an 'on' or 'off' capability, or variable volume control, would make it more attractive, and in addition, what situations they would or would not want to use the device. Members of the fleet driver group suggested that if they had the option to turn it off they probably would, but this would likely cause employment issues. They also suggested they would be more likely to use the device on the open road or on long-distance trips, and unlikely to use it in urban 50km/h areas. The young drivers also suggested they would be in favour of being able to switch the device off. This group suggested they would use the device sometimes if it was optional, particularly in unfamiliar places, when driving long distance, or at risky times of the day for getting speeding tickets. Members of the general sample group also suggested it could be useful for driving in new, unfamiliar areas or on long-distance trips.

In contrast, the older drivers suggested they would not need the on/off function, as if they had bought a device, they would want to use it at all times.

> *'I can't think of a condition where you wouldn't want it unless you are shooting around to the dairy or something like that, but even then, no I don't think there's any point in turning it off.'*

7.8.6 Passengers

Overall, the participants were not particularly concerned with what passengers would think of the device, other than some concerns about embarrassment for the young drivers. The older drivers believed that passengers would find the device a novelty.

7.9 Supportive systems

The participants were generally not in favour of the 'supportive' device being used as it was seen as a system that could intervene and override the driver's control. The biggest concerns around the technology were that it could be dangerous if people were not comfortable about using the override function and that it was taking away too much control from the driver. The older drivers were particularly worried about the safety aspect of this function, concerned that using it would mean their reaction times would become slower, or that it would be too distracting and difficult for the driver when changing between vehicles. The young drivers were also strongly opposed to the idea of an intervening technology and had concerns regarding its safety. This group was more supportive of the haptic throttle technology, but still preferred an advisory system. The fleet drivers also preferred an advisory system only, but thought there could be value in having a supportive intervening system available on the market for individual drivers who may have a preference for this technology. The general sample group was completely against an intervening technology strategy, which was not surprising given their less favourable opinions of the advisory system in general.

7.10 Summary and recommendations

Four focus groups, made up of representatives from different driving populations (young drivers, older drivers, fleet drivers and the general population), explored the acceptability of advisory ISA technology to potential users. The key findings of these focus groups are summarised in this section.

7.10.1 Uptake of the technology

The overall feedback across three of the groups (older, young and fleet driver groups) was positive, suggesting that with the right incentives and with good design, these driving populations would have good uptake of advisory ISA technology. This finding is supported by international findings. However, the general sample group of private vehicle drivers between 25 and 64 years of age were generally dismissive about the devices.

Contrary to many expectations, older drivers were not resistant to the new technology or concerned about using it (however, those who choose to take part in a technology-based focus group may differ from the general older population in this regard). Based on the feedback of the different groups, older drivers would appear to be the easiest group in which to promote uptake of the technology, as they were generally the most supportive. From their own comments, they were also those most likely to comply with speed limits and advisories even without the technology. Previous research would support this finding, as ISA has been found to reduce speeds less in this group, due to their lower baseline speeds (SL Jamson, pers comm, 17 November 2011). The road safety benefit for older drivers is likely to be the ability of ISA to increase their alertness (by highlighting the transition to a different environment), rather than speed compliance.

Fleet drivers are likely to have a good uptake of ISA technology, as most are already monitored to some degree and need to retain their licence for their livelihood. The level of current monitoring depends on the type of role; for professional drivers (eg truck drivers), one offence could be enough to lose their licence, while others, such as tradespeople, do not have quite the same level of compliance required of them (although they still require a good driving record to fulfil their duties). The feature of interest to fleet drivers was the addition of speed advisory information, as the standard speed zone information for many of them is not as important (eg trucks that are speed-limited cannot break open road speeds anyway).

The most resistant group to the technology was the general sample group. These participants felt that the technology would be taking away the driver's control and therefore there would be resistance from the general public towards this type of technology. While all the groups were generally not in favour of too much control over the vehicle by ISA (eg the supportive system), this group was the only one that felt even an advisory system was too controlling of the driver. This has been a common perception in other qualitative research that is available in this area (eg ETSC[22] 2006) and an attitude that is difficult to overcome in ISA uptake, with no clear-cut solution other than informing potential users that this is not the case and ISA takes no control from the driver.

Young drivers (those under 25 years of age) were seen as a target group for this type of technology, due to their high risk profile; however, encouraging ISA uptake within this group would be difficult. The feedback received from the group suggested that ISA would not be popular with this demographic and there would need to be incentives to increase ISA uptake, with strong support for discounts of insurance premium or insurance excess.

7.10.2 Compliance with the technology

Older drivers and fleet drivers stated that they would be the most likely to comply with the warnings of the ISA device if they had one. The young drivers suggested they would be unlikely to comply at all times, which was in line with previous studies where young drivers have admitted to lower compliance (Jamson 2006) and were more likely to turn off or destroy the device (NSW Centre for Road Safety 2010b). However, even intermittent use of the device has been shown to reduce speeds on high-speed roads (SL Jamson, pers comm, 17 November 2011). To improve speed compliance, the design of the feedback was highlighted as having the greatest impact for this group. It would be critical to find the balance between levels of feedback that are sufficient to encourage compliance while avoiding high levels of driver annoyance. This was a view shared by most of the participants.

7.10.3 Target groups

While no group saw themselves as an ideal target group for the technology, most thought there could be some benefit to the community. There was some support for young drivers learning to drive having these devices, although it was also suggested that they should not be taught to *need* the feedback. Professional drivers, in particular taxi drivers, were also suggested, as driving is their livelihood.

The groups generally saw benefit in targeting repeat speeding offenders, but were fairly unconvinced as to their compliance if they were to have the devices. Anecdotal evidence suggested that those close to losing their licence on demerit points may express positive opinions toward having an ISA device fitted, so efforts with this group may be beneficial, at least until they are not in danger of losing their licence any more (SL Jamson, pers comm, 17 November 2011).

7.10.4 Customisation of the device

The majority of previous research on user acceptance of ISA that has been discussed here focused on perceptions following an experience of using a fully developed device. A unique component of this study investigated user feedback on what specific elements people ideally wanted in an ISA device. Being able to customise the device to the individual driver's specifications could increase user acceptance. There was a wide range of preferences for the HMI feedback received, particularly concerning the audio feedback,

[22] European Transport Safety Council.

which led to the suggestion that this could be selected by the individual user, rather than using a ‘one size fits all’ approach.

7.10.5 Relationship with current GPS technology

The other strong finding across the groups was that participants initially struggled to understand the difference between ISA and GPS devices currently on the market. Even when they were clear about the difference, the need for two separate devices was questioned and the suggestion was made that one device that could fulfil both standard GPS and ISA functions would be preferable. While people were not concerned about the new technology, they did not want to be burdened by too many different devices; therefore consideration should be given to integrating ISA with existing technology.

7.10.6 Study limitations

The four focus groups were selected to represent three of the potential user groups that would each have different attitudes and possible barriers to uptake of an ISA system (young drivers under 25, older drivers over 65 and fleet vehicle drivers) and a control sample of the general public.

Recruiting a completely representative sample for focus group research is difficult when participants self-select to take part. As participants were recruited in the first instance through email using the Automobile Association database, and as the subject of the focus groups was a new technology, those who volunteered to take part may have been more interested in new technologies and therefore might not raise some of the issues that may affect other members of the population (eg technophobia). For example, uptake by older drivers in the general community may be lower than indicated in this study. Volunteers for this type of study may also hold particularly strong views (positive or negative), which may be at the extremes of the general population.

8 Advisory ISA participant field trials

8.1 Background

Field trials were undertaken as part of this research project to assess user speed compliance with advisory ISA, the impact of ISA on speed selection, and attitudes to ISA in both a fixed ISA (speed limit information only) and a variable ISA (speed limit and curve advisory information) condition.

Following on from the HMI findings and the focus group results, this study also investigated attitudes towards ISA and the importance of HMI design for balancing both user acceptance and compliance.

The trials were short term (around one hour of driving with each experimental ISA condition) and covered a route that included a range of road types encountered in New Zealand, including urban local roads and arterials, rural roads, expressways and motorways, roads with curved and straight alignments, and with a range of speed limit zones (50km/h, 80km/h and 100km/h). Forty participants were recruited to represent the New Zealand driving public, using a stratified sample of age and gender (based on the representative driving-exposure hours of these demographic groups).

A repeated-measures design was used, where each participant drove their own vehicle over the same route three times (with baseline [no ISA], fixed ISA, and variable ISA) to enable comparisons from their baseline trip that allow a degree of control over extraneous variables (such as individual driving styles). The ISA conditions were also counter-balanced to eliminate any bias due to driver learning/behaviour changes throughout the trial, and factors that would impede free speed, such as other traffic. Following the same rationale, daylight, off-peak, dry driving conditions were selected to reduce the likelihood that a participant's speed would be impeded. Questionnaires were used to examine user perceptions of ISA technology, preference between variable and fixed ISA after exposure to each condition, and the elements of the HMI design that were seen as positive or negative. Further details are contained in appendix D.

8.2 Method

8.2.1 Study route

The route used in the experimental trials was near Wellington and included a mixture of road environments, including 50km/h, 80km/h and 100km/h speed zones, local roads, rural state highways, expressways and motorway as shown in figure 8.1. This included some winding sections of road in the rural sections, where speeds were likely to be constrained by the geometry. The route was 56km long, took about an hour to drive one circuit, and included nine speed limit changes, 14 advisory speed curves, and one speed-hump zone on Bell Road, as outlined in table 8.1.

Study participants travelled in an anti-clockwise direction from Opus Central Laboratories on Hutt Park Road, on local roads through the Hutt Valley before entering State Highway (SH) 2 at Fairway Drive. The route then followed SH58 and SH1 before turning back onto SH2 at the Ngauranga Interchange, and returning to Opus Central Laboratories, as shown figure 8.2.

Figure 8.1 Photos of parts of the trial route

a) Two-lane rural state highway with advisory curve in distance

b) Rural two-lane state highway coastal section with tight curves

c) Four-lane expressway with at-grade intersections

d) Motorway

Figure 8.2 Route used in experimental trials

Table 8.1 Attributes of the experimental trial route (trial route sections in relation to figure 8.2)

Trial route section	Attributes
1 Opus Central Laboratories → Hutt Park Road → Gracefield Road → Bell Road → Waiwhetu Road → Naenae Road → Daysh Street → Fairway Drive	• 50km/h • speed-hump zone on Bell Road • two 25km/h advisory speed curves
2 SH2	• 100km/h expressway standard road with several at-grade intersections
3 SH58 open road	• 100km/h rural two-lane road with four advisory speed curves ranging from 75km/h to 85km/h
4 SH58 coastal and urban	• 80km/h winding coastal two-lane road with five advisory curves ranging from 35km/h to 45km/h • 50km/h urban road with one 35km/h advisory speed curve
5a) SH1	• 100km/h expressway • 100km/h motorway • 80km/h default speed on motorway with variable-message speed signs
5b) Centennial Highway (ramp between SH1 and SH2)	• 100km/h with one 75km/h advisory speed curve
6 SH2	• 100km/h expressway • 80km/h expressway
7 Petone off-ramp → The Esplanade → Waione Street → Seaview Road → Parkside Road → Hutt Park Road → Opus Central Laboratories	• 50km/h local roads, with one 45km/h advisory speed curve at Petone off-ramp

It is acknowledged that due to the nature of the experimental trials, which were of short duration, that drivers' speed choices may have been different from travel undertaken on longer journeys and on more remote rural roads.

8.2.2 Human–Machine Interface (HMI) design

The development of the HMI for the trials formed an important aspect of the experimental design, as there was an appreciation that a poor HMI could have negative effects on the trial outcome. This was reinforced by the focus group findings (see chapter 7), which concluded that achieving a balance between a level of feedback that was sufficient to encourage compliance while avoiding high levels of driver annoyance was critical.

While a number of ISA trials have been undertaken internationally, there appears to have been little study undertaken on HMI and the effect that this can have on both user uptake and compliance. There has been no specific work on usability for an ISA display, and while there are general principles as outlined in the European Statement of Principles on HMI, they are not system specific (SL Jamson, pers comm, 11 August 2011). The importance of HMI design was emphasised in the user perceptions and incentives findings that were discussed in the literature review (see chapters 3 and 4), which recommended that further work was needed in this area.

While a user-customisable HMI is likely to be preferable for a full-scale deployment of ISA (in line with the study focus group feedback on acceptability), such flexibility in HMI was outside the scope of this study, particularly as the devices were only to be used by the test subjects for a short period of time. A fixed HMI was developed, using a Dreevo2 device, which uses the Speed Alert software application and is a product of Smart Car Technologies Pty Ltd in New South Wales, Australia. The same device was used for the ISA trials in Lancashire and the New South Wales RTA trials (NSW Centre for Road Safety 2010b).

The Dreevo2 is a wireless-enabled device that is attached to the dashboard or windscreen of the vehicle, using suction cups (see figure 8.3). For this experiment, the device provided the driver with speed limit information and visual and auditory warnings when the speed limit was exceeded, using a 1Hz poll frequency. It also recorded the driver's speed on a Secure Digital (SD) card. The device could use the cellular phone GPRS network for speed limit map updates and could send vehicle speed information back to the Speed Alert server; however, this functionality was not enabled for this trial, as information was simply stored on the unit's SD card and downloaded. The device's SD card was also used to store road centreline and speed zone data for the trial route. The small screen size of the device (120mm x 82mm x 26mm) meant that it was unobtrusive yet still easily visible to the driver.

Figure 8.3 ISA device in use on the trial route

a) Driving below the speed limit in a 100km/h zone

b) Exceeding the speed limit in a 50km/h zone

c) Driving below the advisory speed on a 45km/h advisory curve

d) Exceeding the advisory speed on a 45km/h curve

For the experimental trials, the following three modes were used:

- Mode 1: The device recorded driving behaviour, but with a black screen; ie with just the navigation bar with the clock on it displayed (baseline condition).
- Mode 2: The device displayed speed limit zones and provided feedback when the speed limit was exceeded, but with advisory zones switched off (fixed ISA condition).

- Mode 3: The device was at full functionality, with speed limit zones and curve advisory alerts/warnings (variable ISA condition).

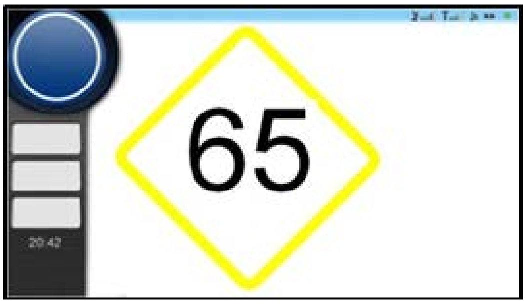
Six Dreevo2 devices were used; the three respective modes were programmed into two devices each, and these were rotated between the participants during the trial. The experimental trials were also recorded on video through a windscreen-mounted device, in order to capture the driver view of the upcoming road environment. A second small external camera was mounted on the interior of the passenger door, to provide a side profile of the driver. The video device was a VISIONDRIVE Black Box (VD-700) device with external camera (400R).

Various HMI options had been considered by the Steering Group and focus group discussions, including the display of pictorial advisory symbols and the display of advisory information in addition to speed limit information, as shown in figure 8.4.

Figure 8.4 Example HMI options considered by the Steering Group

a) Speed limit with pictorial advisory speed symbol

b) Advisory speed with yellow border masking the speed limit image



The options were constrained by the study budget available for software development, and there were also some limitations based on what Smart Car Technologies advised was technically feasible for their software, such as the use of a flashing symbol to indicate speeding.[23] Similarly, there were restrictions on the HMI used during and in advance of advisory speed zones. In particular, the advance warning distance and the speed triggers could not be varied.

Focus group feedback suggested that the audio should be distinctive, midrange in pitch, and that it could be either verbal or a non-musical noise. Selecting suitable beep-style sounds proved difficult, as the sound had to be strong enough to be effective without being too irritating, as well as being distinct from other sounds encountered in the driving environment. Consequently the proposed 'clinking glasses' sound, which the focus groups felt was not loud enough, was replaced by the 'AMFM' beep sound[24], and the voice recording stating 'Speed change ahead' was also developed as an advance warning sound. Focus group feedback suggested that this would be less confusing than using yet another beep-style sound. Other changes made on the basis of focus group feedback included the adoption of a solid yellow diamond that matched road signs (see figure 8.5c), rather than the diamond with a yellow border (see figure 8.4b above).

The visual HMI used in the study trials is shown in figures 8.5a–d and 8.3a–d.

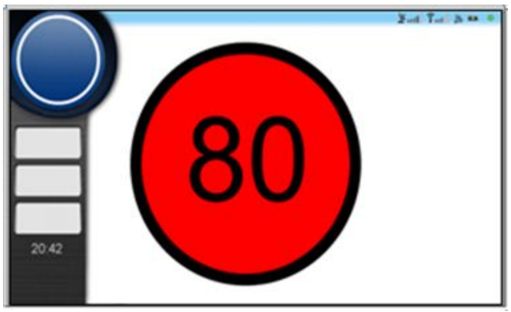
[23]The study team was advised that a constant rate of flashing could not be implemented reliably.

[24] Described as an 'AMFM beep' and sourced from www.alwaysfree.nl/free_sound_effects/beeps/slides/Am_Fm_Beep.html

Figure 8.5 Examples of the HMI used in the trial

a) The speed limit roundel shows a red border while travelling below the speed limit

b) A red symbol is displayed while exceeding the speed limit



c) Advisory speed diamond with yellow symbol while travelling below the advisory speed

d) A red symbol while exceeding the advisory speed

The complete HMI, with visual and audio, can be summarised as shown in table 8.2, in order of escalating feedback.

Table 8.2 Summary of the HMI used in the experimental trials[a]

Situation	HMI description
Travelling at or below speed limit	Speed limit roundel displays speed limit (no audio)
Approaching speed limit change	Single ‘speed change ahead’ voice message triggered 150m in advance of the speed limit sign
At speed limit change	Single ‘jungle drums’ sound, and speed limit roundel changes to display new speed – triggered at the location of the speed limit sign
Speeding, above speed limit to 3km/h above speed limit	Speed limit roundel is filled in red (no audio) as soon as speed limit threshold is reached (ie 50km/h, 80km/h or 100km/h speed zone)
Speeding >3–8km/h above speed limit	Single beep repeated continuously, and speed limit roundel filled in red
Speeding >8km/h above speed limit	Triple beep repeated continuously, and speed limit roundel filled in red
Approaching advisory speed zone	Single ‘AMFM’ beep triggered 75m in advance of the start of the advisory speed zone
At start of advisory speed zone	Speed limit roundel replaced by yellow diamond displaying advisory speed
Travelling above advisory speed to 15km/h above advisory speed	Advisory speed diamond filled in red (no audio)
Travelling >15–30km/h above	Single beep repeated continuously, and advisory speed diamond filled

Situation	HMI description
advisory speed	in red
Travelling >30km/h above advisory speed	Triple beep repeated continuously, and advisory speed diamond filled in red
Travelling above speed limit while advisory present	Speeding audio signals (single/triple beep) activated and repeated continuously; red advisory speed diamond still displayed
At end of advisory speed zone	Yellow diamond reverts back to speed limit roundel (no audio)
Insufficient GPS coverage	'?' displayed inside speed limit roundel
Out of speed limit map coverage	'Out of Map Coverage' displayed on white screen

a) 'Speeding' warnings are activated until the driver reduces speed to below the threshold.

Furthermore, no buffer was applied to the GPS speed to take speedometer readings into account (which typically read 3% over the actual speed travelled on average). This means that the speed used by the GPS to trigger the HMI changes was likely to show a higher value than the speed displayed on the participants' speedometer. The study test participants were made aware of this possibility.

For this trial, the Steering Group decided not to include advisories that did not have a recommended speed (eg pedestrian crossings) or temporary advisories (eg temporary school zones or variable speed limits). Where variable speed limits were present on the trial route, these were coded at their default speed limit, as was done in the New South Wales RTA trial. To mitigate the effects of this, trials were planned to occur outside of times of major road works, and if trials occurred when a different variable speed limit was displayed, this data was omitted from the analysis.

The speed limit HMI used was the same as that used in the New South Wales RTA ISA trials, except that speedometers were not adjusted and a voice with a New Zealand accent was used for the 'speed change ahead' warning. A number of alterations, including the use of percentage-based speeding thresholds, were considered and rejected. However, as advisory curves were not part of the New South Wales RTA trials, this aspect of the HMI was designed specifically for this study.

8.2.3 Location of advisory zone and advance warnings

As shown earlier in table 8.2, in addition to the audible 'beep' used to warn drivers that they were speeding, audio warnings were also used 150m in advance of speed limit changes and 75m in advance of advisory speed signed curves.

The 150m 'speed change ahead' warning distance was determined by the device calculating different deceleration rates, reaction times and speed drops, whilst ensuring they were not too far in advance of the speed limit change, which would mean that drivers might not react to it. At 100km/h, 150m gives a driver time to slow to 50km/h, with a two-second reaction time and a deceleration rate of $3m/s^2$. For advisory speed zones, a shorter advance warning distance of 75m was used, to ensure drivers would connect the warning sound with the curve ahead. There were physical roadside signs located prior to the curve at all advisory speed zones (however, the distance of the physical signs before the curves did vary, to maximise the sight distance of the sign before the curve). While the warning for advisory speeds at curves would ideally be sounded while in view of the roadside curve advisory sign, this was not always possible due to constraints in the Speed Alert software, with the beep sounding after the sign in some instances.

These advance warning distances, as well as speed limit change points and advisory speed zone boundaries, acted as a screen-line, with the Dreevo2 device sounding the audio warning at the first poll after it passed the screen-line. The 1Hz poll frequency of the device meant that as much as 28m could pass before the audio warning was activated. For this reason the start points of all speed zones were moved 30m in advance of the position of the speed limit or advisory sign.

The start and end points of each advisory speed zone were based on the start and end of the curve as defined in the Out-of-Context Curves data (sourced from a table in the NZTA's RAMM of all curves where the minimum radius within the curve drops below 400m). Note, the curve length was taken from where the radius dropped below 800m (or reversed direction). Where there were consecutive out-of-context curves, the advisory speed zone continued until the end of the last out-of-context curve. This meant that the curve advisory stimulus continued after the curve apex through to the end of the curve, which may have impacted on driver acceptance, as they may have felt unnecessarily constrained at times.

The audio threshold for a single repeated beep was set at 15km/h above the advisory speed, based on the midrange of a finding by Koorey et al (2002) that suggested 85th percentile curve speeds would be between 10km/h and 20km/h above the posted advisory speed. The triple-beep threshold was set at double the single-beep threshold (at 30km/h). This was consistent with a study of 28 curves by Bennett (1994), which found 85th percentile curve speeds to be between 10km/h and 28km/h higher than the posted advisory speed, with both studies suggesting that drivers simply increase the advisory speed by a fixed amount and traverse the curves at this higher speed, even though a multiplicative increase may be more appropriate. Barnes and Thompson (1984) found that drivers' mean observed speeds increased at a faster rate than posted advisory speeds. However, a pilot trial of the ISA equipment for this study found that percentage-based audio thresholds tended to be too low for lower advisory speeds; eg a 20% single-beep threshold would mean a 35km/h advisory would beep at 42km/h and an 85km/h would beep at 102km/h. While Koorey et al (2002) developed linear relationships between observed speed and posted advisory speed, it was not possible to trial this here due to limitations in the Speed Alert software.

In addition to advisory speed warnings on curves, an advisory speed warning (using the same diamond-shaped symbol) was provided to the driver in the speed hump-zone on Bell Road, where there are eight speed humps. The first six speed humps have an average spacing of about 120m between them, and there is a 220m spacing between the final speed humps. Each speed hump has a 15km/h advisory speed posted at the location of the speed hump. However, this advisory speed is intended as a speed hump negotiation speed, rather than for the whole speed zone, so a higher advisory zone speed was required. Charlton and Baas (2006) and Basil et al (2011) found that average speeds vary with speed hump spacing, and a 120m spacing gives a mean speed of about 37km/h. Due to restrictions with the Speed Alert software, the same advisory beep thresholds of 15km/h and 30km/h were used. As such, an advisory speed of 35km/h was chosen, resulting in the activation of a single warning beep at 50km/h. This seemed reasonable, as the purpose of the speed humps is to act as a traffic-calming device to keep speeds below the 50km/h speed limit.

It should be noted that this HMI was specifically developed to be suitable for this trial. There are a number of additional aspects that would need to be considered if ISA were to be deployed in New Zealand. These include, but are not limited to, the volume of the audio and how this might interact or override other warnings and the entertainment system; the use of flashing symbols; appropriate warning distances; warning sounds used; duration of repeated warnings; trigger thresholds; the possible inclusion of real-time advisories and warnings; and the ability for users to customise the device.

8.2.4 Participant sampling

Participants were recruited through the AA email databases (refer to appendix section D.1 for a copy of the recruitment email). An invitation to participate was sent to 4000 randomly selected email addresses from postcodes in the Hutt Valley region. This invitation outlined what was required in terms of time commitment and travel, the demographic characteristics of those who could take part, and the reimbursement provided to successful applicants ($250 MTA vouchers for completing the whole trial). Participants were asked to contact the researchers if they were interested in taking part, and they were then sent the screening questionnaire outlined in section 8.2.6. More than 350 people responded to the advertisement, and 145 people completed the screening questionnaire.

The provision of a large monetary incentive for completing this study was seen as necessary to ensure that a range of the population could be recruited, not just those with a strong opinion or interest in technology such as ISA. It also provided a larger sample pool to select from to achieve the required sample.

Based on participant responses, a stratified sample of 40 drivers was selected. The number in each age group and gender was based on the percentage of hours driven by drivers in each demographic group (using the Ministry of Transport's 2011 *Household travel survey data 2007–2010*). This method of sampling was selected to enable the generalisation of the trial results to the New Zealand driving population as a whole. The demographic spread of the sample is included in table 8.3 below.

Table 8.3 Sample numbers in each demographic for a stratified sample

Females				Males			
Age group	Million hours	% of total hours	Sample size	Age group	Million hours	% of total hours	Sample size
18–24	40	4.90	2	18–24	54	6.63	3
25–29	31	3.80	2	25–29	39	4.79	2
30–34	33	4.05	2	30–34	42	5.15	2
35–39	41	5.03	2	35–39	49	6.01	2
40–44	45	5.52	2	40–44	53	6.50	3
45–49	46	5.64	2	45–49	55	6.75	3
50–54	33	4.05	2	50–54	46	5.64	2
55–59	28	3.44	1	55–59	42	5.15	2
60–64	20	2.45	1	60–64	34	4.17	2
65+	30	3.70	1	65+	54	6.63	2
Total	**347**	**42.58**	**17**	**Total**	**468**	**57.42**	**23**

Participants were selected in line with this stratification and based on their availability to take part in each scheduled trial date.

Comparisons were made between the selected trial participants and the total pool of participants who completed the screening questionnaire, to explore whether there was any bias in the selected sample. The results showed there were no significant differences between the two samples on either the 'Attitudes to speed' scale ($t(137) = 1.16$, $p = .25$) or the Intentions to Speed scale ($t(138) = -.09$, $p = .92$), indicating there was no obvious bias concerning speeding attitudes in the selected sample compared to the total sample. (Further information regarding these scales is provided in section 8.2.7.)

Several questionnaire items based on items from the Ministry of Transport's *Public attitudes to road safety* (2010) survey results were completed by participants in this trial, to enable a comparison of the sample to the general New Zealand public. (More information regarding the questionnaires utilised in the trial is provided in section 8.2.6.) As shown in table 8.4, the current sample significantly differed from the general New Zealand public on only one item. Participants in the current sample were significantly less likely to agree with item 13, indicating they had a higher perceived risk of speeding behaviour causing accidents than the general public (which may imply this study's results are relatively conservative).

Table 8.4 Comparison of trial sample against the general New Zealand population on MoTransport items

Item	Significance
Q13: There isn't much chance of an accident when speeding if you are careful	p = .02
Q14: The risk of being caught speeding is small	p = .11
Q15: Penalties for speeding are not very severe	p = .19
Q16: Most people who get caught speeding are just unlucky	p = .24
Q17: Enforcing the speed limit helps lower the road toll	p = .88
Q18: How much do you like driving fast on the open road?	p = .66

8.2.5 Procedure

Trials were held during February and March 2012, with four weekend trial days and three weekday trial days. Six of the trials had six participants and one had four participants. Sessions began at 9am on weekends and 10am on weekdays, with the all drivers on the course within one hour of the start time. Departures were staggered to allow time to transfer devices and to space participants along the route.

On arrival for the field trial, participants as a group were shown two introductory videos. The first explained how the ISA devices worked and the difference between the different forms of ISA they were testing (fixed and variable). It also explained the different HMI components. The second video then outlined the test route, with clips of every major intersection of the journey as well instructions to record the freephone number on which to contact the researchers if they had any difficulties with directions or technical issues.

Before the first run of the trial route, participants were given a consent form to complete, as well as a baseline questionnaire (outlined in section 8.2.6). Participants were assigned counterbalanced ISA conditions and after each run, completed a survey examining attitudes and preferences around the ISA device version they had just used. Two of each ISA type and two baseline units (with no ISA to act as a control) were rotated between the six participants across the trial day. The assignment of participants to each ISA condition is outlined below in table 8.5.

Table 8.5 Counterbalanced ISA conditions

Run number	Participant number					
	1	2	3	4	5	6
1	Fixed	Variable	Baseline	Variable	Fixed	Baseline
2	Variable	Baseline	Fixed	Fixed	Baseline	Variable
3	Baseline	Fixed	Variable	Baseline	Variable	Fixed

There was no familiarisation phase with the devices in the participants' vehicles. The first section of road was a low-traffic road in a 50km/h speed zone, which minimised any health and safety issue in the initial phases of using the device.[25] The use of a within-subjects design allowed for the comparison of driver

[25] An internal ethical review was conducted prior to the trials. The only change based on this review was the decision not to place observers in the vehicle with the drivers during the trial. Instead, any observational data was to be collected by video footage.

behaviour across every condition, controlling for individual variation in driving behaviour. Counterbalancing helped to remove any effects of condition order (eg whether participants drove faster in the baseline period if they completed this before either ISA condition), as well as reducing error due to varying conditions during the trial (such as traffic). Conditions were always dry, daylight, and in off-peak traffic (between 10am and 2:30pm) to maximise the likelihood that a driver's speed would not be impeded.

8.2.6 Questionnaires

All those who applied to take part in the study were asked to complete a screening questionnaire that collected demographic data and confirmed their ability to take part in the field trials. In addition, these volunteers were asked eight questions about their attitudes to exceeding 100km/h speed limits and a further three questions about their plans, intentions and desire to exceed the 100km/h speed limit on motorways. The screening questionnaire is included in appendix section D.3.

Before having any experience using an ISA device, participants completed a measure of perceptions of ISA and attitudes toward speed limits and hazard advisory limits at curves (see appendix section D.4). The general speed attitude measures were based on items from the survey results of the Ministry of Transport's *Public attitudes to road safety* (2010), as mentioned above. The perceptions of ISA questions were largely based on expert reviewer recommendation (SL Jamson, pers comm, 10 January 2012).

Following each run of the course, participants completed additional questionnaires about their experience with the device they just used (see appendices D.5, D.6 and D.7). These questionnaires included getting a subjective report of the road conditions (eg level of traffic and its effect on the driver's speed), and a repeat of the measures used in the baseline of perceptions of each ISA device. There were also specific questions around the HMI design of each device and any changes the participant suggested would make them more likely to use the device. Some of the items in these questionnaires also came from communication with another researcher in the area (SL Jamson, pers comm, 10 January 2012), while the specific HMI-related questions were developed for this study by the authors.

Finally, participants completed an overall assessment of the ISA devices once they had completed all three runs of the course (see appendix section D.8), which included questions about other advisories they would like added to the device and the driver groups they felt would get the most benefit from using it. Additional questions on driving experience, route familiarity and fleet vehicle use were also included.

8.2.7 Speed attitudes scales

Four scales were formed from various questionnaire items. Summary statistics for these scales are provided in table 8.6, and table 8.7 displays statistics for the individual items (with appropriate items reversed so higher scores indicate less-cautious attitudes towards speed on all items). The 'Attitudes to speed' scale was used to separate drivers into those who overall believed speeding to be a negative thing, as opposed to those who were supportive/neutral toward speeding behaviour (see section 8.3.3).

Table 8.6 Scale summary statistics

Scale	No. of items	N	Mean	Min.	Max.	Std. deviation	Cronbach's alpha (α)
Attitudes to speed	8	39	22.9	8	44	9.8	.94
Intentions to speed	3	39	7.4	3	18	4.3	.89
MoT speed attitudes	4	40	8.4	4	15	2.7	.68
Curve advisories	5	38	13.2	7	20	3.0	.74

Table 8.7 Scale items

Scale item	N	Mean	Min.	Max.	Std. deviation
'Attitudes to speed' scale (Exceeding the 100km/h speed limit on the motorway would be … (scale range of 1–7)					
Unsafe/safe	40	2.7	1	6	1.6
Useful/useless (reversed)	39	3.1	1	6	1.6
Unsatisfying/satisfying	39	3.0	1	6	1.5
Beneficial/harmful (reversed)	39	2.9	1	6	1.7
Not enjoyable/enjoyable	39	3.1	1	6	1.5
Positive/negative (reversed)	39	2.7	1	6	1.5
Reckless/cautious	39	2.5	1	5	1.2
Good/bad (reversed)	39	2.8	1	5	1.2
Intentions to speed scale (from 1 = strongly disagree to 7 = strongly agree)					
I would intend to exceed the 100km/h speed limit on a motorway	39	2.4	1	6	1.5
I would want to exceed the 100km/h speed limit on a motorway	40	2.7	1	6	1.5
I would plan to exceed the 100km/h speed limit on a motorway	40	2.4	1	6	1.6
MoT speed attitudes scale (from 1 = strongly disagree to 5 = strongly agree)					
There isn't much chance of an accident when speeding if you are careful	40	1.8	1	4	.73
The risk of being caught speeding is small	40	2.3	1	4	.99
Most people who get caught speeding are just unlucky	40	2.2	1	4	.93
Enforcing the speed limit helps lower the road toll (reversed)	40	2.1	1	5	1.0
Curve advisories attitudes scale (from 1= strongly disagree to 5 = strongly agree)					
Curve advisories are just a recommendation	38	3.5	2	4	.80
I don't need to drive as slowly around corners as other drivers	38	2.6	1	4	.86
Only unconfident drivers drive at the advisory speed around curves	38	2.5	1	4	.86
Experts set the speed advisories at curves so I trust them as accurate (reversed)	38	2.6	1	5	.94
Curve advisories are set for trucks, not regular vehicles	38	2.1	1	4	.85

8.2.8 ISA data handling

During the data cleaning process, some issues and inconsistencies in the data recorded by the ISA devices were identified. These are summarised below:

- *Speed zone transition error*: Several of the ISA devices failed to transition cleanly between two speed zones (eg from an 80km/h speed zone to a 50km/h speed zone). At this transition, the ISA device logged one data point of the new speed zone, followed by one data point of the old speed zone before completely transitioning into the new speed zone. Where this was the case, these two inaccurate speed zone data points were removed for these participants.
- *Speed zone data loss*: Several of the ISA devices lost all speed zone information (logging the speed zone as 0) for varying lengths of time at various points along the route. This speed zone loss occurred for 3.4% of the total data points recorded and did not appear to relate to GPS signal strength (eg the

number of satellites), as the problem was still apparent when data with only 10 or more satellites was used. As speed zone data loss did not affect the accuracy of any of the other data points, these participants were not excluded.

- *Unexplained missing data*: Several of the ISA devices failed to log any information at various points along the route. In some instances this data loss continued until the end of the participant's run, whereas in other instances the data loss was experienced for shorter periods (eg seconds or minutes) and then returned. The latter was more difficult to identify. In some cases it is believed that failure of the ISA device power cables could have been responsible for this data loss, but this is difficult to confirm. For four participants there was substantial missing data observed for the baseline condition (between 80% and 90% of the run), so these participants were excluded from all analyses of the whole route or sections that were particularly affected. For another four participants, the missing data observed was from set parts of the test route, so these participants were only excluded from analyses that included the parts of the route where there was incomplete data on any of their three trial runs.
- *Outliers*: Outliers in the data were identified by standardising the data (for each speed zone and by ISA condition) and examining Z scores that were above 3.29 or below -3.29. Where this was the case this data was replaced with a calculated speed of +/-3 standard deviations from the mean speed (following the process outlined by Field 2009). Overall, this replaced only 1.14% of the speed data (N=7577; the majority of this data was low-speed data, with only 23 speed data points removed due to high speed, all of which were in the 50km/h speed zone).[26]

8.2.9 GPS sensitivity

Based on the data received from the first six participants, the GPS data coordinates were updated once every 1.09 seconds when the vehicle was moving. For the purposes of these analyses, each data point was therefore treated as one second for calculating overall journey times.

8.2.10 Data analysis

Analysis techniques included repeated-measures ANOVAs[27] (with repeated-measures *post hoc* t-tests) to examine mean differences between ISA conditions (ie baseline, fixed ISA and variable ISA). Friedman's ANOVAs (with Wilcoxin *post hoc* tests) were used to examine differences in the proportion of the trip driven, by speed compliance category (ie under the speed limit, between speed limits and 3km/h over, between 3km/h and 8km/h over, and more than 8km/h over). Where Mauchly's test indicated that the assumption of sphericity had been violated, the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. Where the effect size for this test was less than 0.2, indicating a low effect or small mean difference (Cohen 1998), *post hoc* tests were conducted using the Bonferroni adjustment.

In the questionnaire analysis, scale reliability was used to determine whether attitudinal items were measuring the same underlying construct using Cronbach's Alpha.

[26] Other data filters were trialled to enable a better representation of free-speed driving conditions, but these filters did not stand up to validity testing.

[27] Analysis of variance.

8.3 Findings

8.3.1 Sample

In total, 40 participants completed the trial. Just over half (57.5%, N=23) were male, leaving the remaining 42.5% (N=17) female (to fit with the overall driving profile in New Zealand). The mean age of the sample was 42.4 years. Table 8.8 displays driving experience measures for the sample.[28] As is shown in the table, over half the sample had over 20 years of driving experience and only one participant had never driven the trial route before participating in the trial.

Table 8.8 Sample demographics regarding driving experience

	Frequency
Years of holding a driver licence	
2–5	2 (5.9%)
5–10	4 (11.8%)
10–15	3 (8.8%)
15–20	7 (20.6%)
20+	18 (52.9%)
Total	**34 (100.0%)**
Route familiarity	
Very familiar (drive it regularly)	13 (40.6%)
Somewhat familiar (drive it occasionally)	18 (56.3%)
Not familiar at all (have never driven it)	1 (3.1%)
Total	**32 (100.0%)**
Number of kms driven per year	
1000–5000	5 (15.6%)
5000–10,000	5 (15.6%)
10,000–15,000	15 (46.9%)
15,000–20,000	3 (9.4%)
20,000–25,000	3 (0.4%)
25,000–30,000	1 (3.1%)
Total	**32 (100.0%)**
Road types most commonly driven	
Mainly urban/suburban roads	19 (59.4%)
Mainly open/rural roads	0 (0.0%)
A mix of both	13 (40.6%)
Total	**32 (100.0%)**

A comparison of speed data (table 8.9) from the sample of drivers taking part in the trial, and results from the Ministry of Transport's national speed survey at two sites on straight roads along the route (P Phipps, pers comm, 16 May 2013), indicates a slight experimental bias.

[28] These measures were added after the first trial day, so were not collected for the first six participants.

Table 8.9 Comparison of national speed survey data (P Phipps, pers comm, 16 May 2013) with ISA field trial baseline free[29] speed results, open road

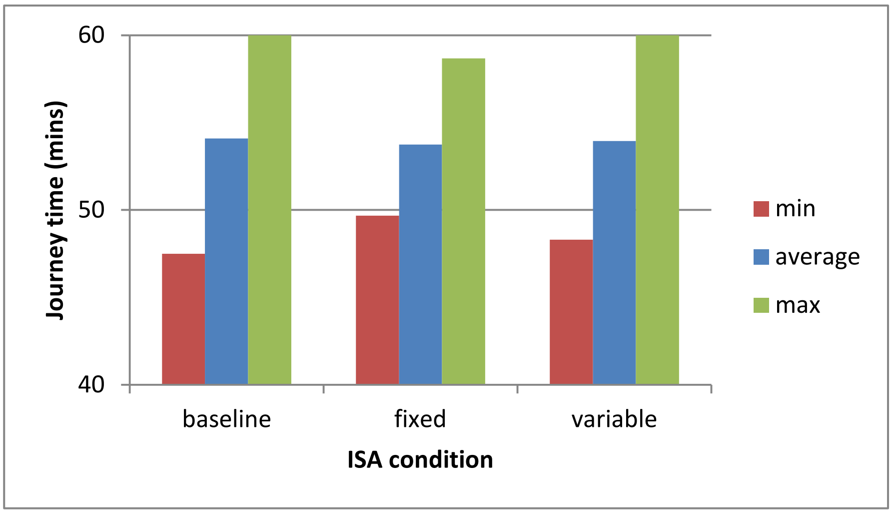
Speed survey site[30]	National speed survey 2012			ISA field trial baseline		
	Mean free speed (km/h)	85th percentile free speed (km/h)	Percentage exceeding the speed limit	Mean free speed (km/h)	85th percentile free speed (km/h)	percentage exceeding the speed limit
SH58 site	88.1	97	5.9%	89.6	95	0%
SH1 site	97.6	105	34.5%	97.3	102	10%

8.3.2 Effects of ISA

8.3.2.1 Effects of ISA on journey times

Overall there was less than a minute's difference in the overall average journey time of almost an hour between the three ISA conditions, as illustrated in figure 8.6, which shows the mean, minimum, and maximum journey time, by condition, across the whole route. The results of the statistical analysis[31] revealed that the overall trip time differences were not significant between ISA conditions ($F(1.23, 46.72) = 2.783$, $p = .09$). The range of journey times was reduced in the two ISA conditions, particularly the fixed ISA condition, giving a more uniform speed profile than the baseline condition.

Figure 8.6 Overall journey time, by ISA condition



In addition to the effect on journey time overall, the effect of ISA on journey times for each road section type is displayed in figure 8.7. The overall journey time was slightly longer in the ISA conditions than in

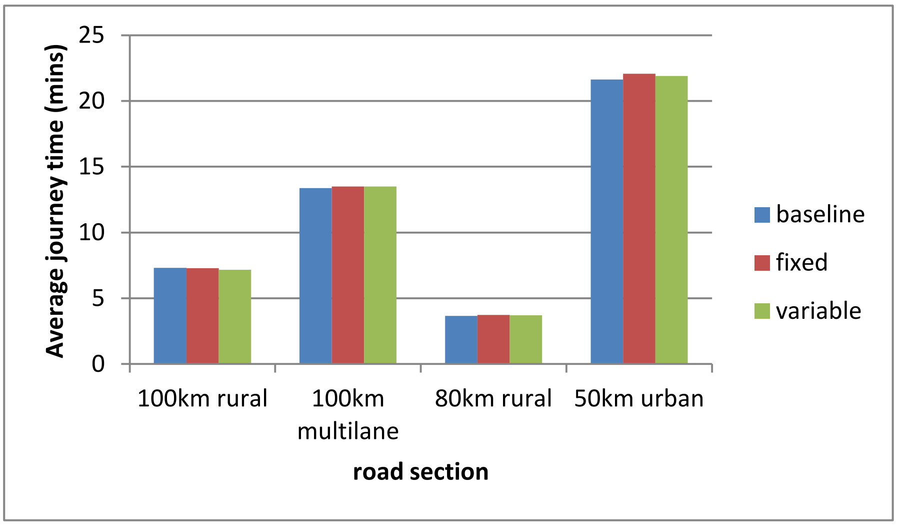
[29] Free speeds were determined by removing speeds that were less than 75% of the speed limit; also, the results from four participants were removed due to missing data.

[30] To maintain the integrity of the speed survey sites, the location of these sites has not been reported.

[31] A one-way repeated-measures ANOVA was used to explore differences between travel times by ISA condition. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(2) = 31.57$, $p < .001$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .63$).

the baseline in all road sections except the 100km/h rural; however again, the differences between these conditions were very small.[32]

Figure 8.7 Overall journey time, by ISA condition, for each road section type



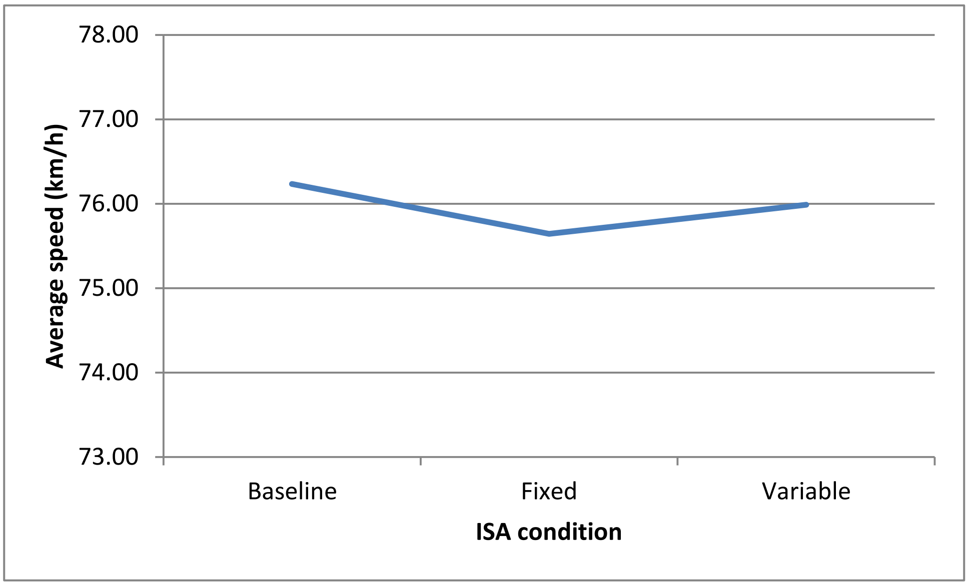
8.3.2.2 Effects of ISA on speeds

Figures showing speeds for each ISA condition for the whole route and for each road section type are shown in this section, and table 8.10 summarises the results of the effects of ISA on mean speeds. In each case, *post hoc* tests were conducted using the Bonferroni adjustment, after finding a small effect size using one-way repeated-measures ANOVA with degrees of freedom corrected using Greenhouse-Geisser estimates of sphericity; the Greenhouse-Geisser estimates were used following the finding that the assumption of sphericity had been violated using Mauchly's test.

Overall mean speeds, by condition, can be seen in figure 8.8, which shows the baseline to have higher mean speeds than fixed ISA, and with variable ISA being between the two. The statistical measures are summarised in table 8.10.

[32] Statistical significance was not tested.

Figure 8.8 Mean speeds, by ISA condition, over the trial route



Figures 8.9–8.12 show the mean speeds, by ISA condition, for each road section.

Figure 8.9 Mean speeds, by ISA condition, in 100km/h single-lane carriageway rural zones

Figure 8.10 Mean speeds, by ISA condition, in 100km/h multilane zones

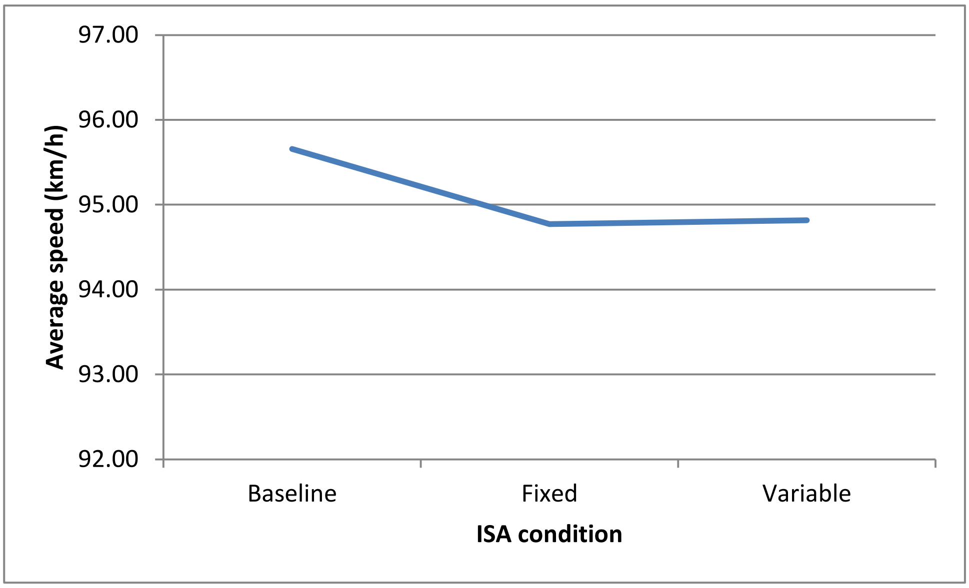


Figure 8.11 Mean speeds, by ISA condition, in 80km/h speed zones

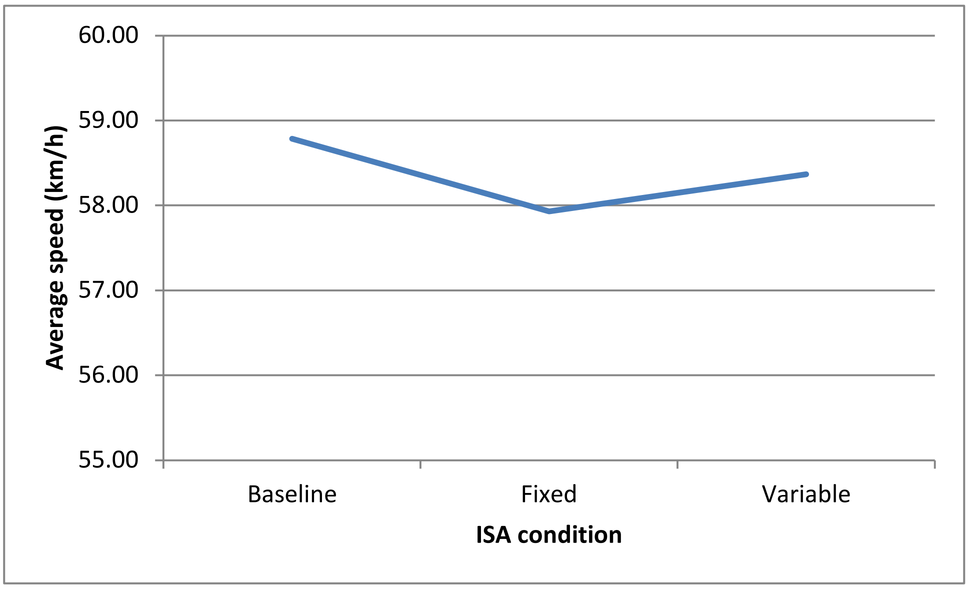
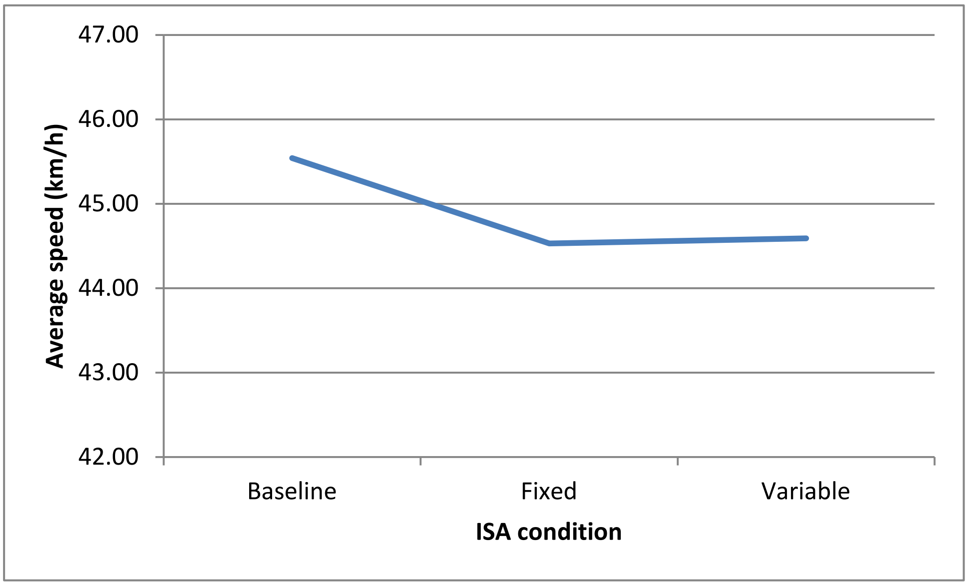


Figure 8.12 Mean speeds, by ISA condition, for 50km/h speed zones



Overall, each road section type in figures 8.9–8.12 and table 8.10, with the exception of the 100km/h rural single-lane carriageway, shows that the baseline ISA condition mean speed was statistically significantly faster than those in both the fixed and variable ISA conditions. For the 100km/h rural single-lane carriageway, the results were counter-intuitive, with both the fixed and variable ISA mean speeds being significantly faster than those in the baseline.

However, there was more variation between the fixed and variable ISA conditions. Variable ISA mean speeds were faster than fixed ISA on both the 100km/h and 80km/h rural single-lane carriageway sections. For the 100km/h rural multilane (expressway and motorway) sections there was no statistically significant difference in mean speeds between the fixed and variable ISA conditions. However, in the 50km/h urban sections, variable ISA mean speeds were significantly faster than those in the fixed ISA condition.

Table 8.10 Effects on speeds, by ISA condition and road section[a]

Route section, by speed zone and road type	Mean speed, M; and standard deviation, SD (km/h)			Results of statistical significance tests			Statistical test details
	Baseline	Fixed ISA	Variable ISA	Fixed v baseline ISA	Variable v baseline ISA	Fixed v variable ISA	
Overall trial route	*M* =76.23 *SD* =22.25	*M* =75.64 *SD* =22.33	*M =75.99* *SD =22.46*	Baseline $p < .001$	Baseline $p < .001$	Variable $p < .001$	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 2003.09$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .99$ $F(1.98, 414190) = 714.97$, $p < .001$ Effect size: *<0.2*, Partial $\eta^2 = .003$ Test used: *Post hoc* test using Bonferroni adjustment
100km/h rural single-lane carriageway	*M* =83.69 *SD* =9.28	*M* =84.23 *SD* =9.36	*M* =85.38 *SD* =9.31	Fixed $p < .001$	Variable $p < .001$	Variable $p < .001$	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 1743.32$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .95$ $F(1.91, 67121.11) = 565.79$, $p < .001$ Effect size: *<0.2*, Partial $\eta^2 = .016$ Test used: *Post hoc* test using Bonferroni adjustment
100km/h rural multilane (expressway & motorway)	*M* =95.66 *SD* =7.47	M =94.77 SD =7.10	M =94.82 SD =7.31	Baseline $p < .001$	Baseline $p < .001$	No significant difference $p = .27$	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 119.75$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .99$ $F(1.99, 111747.26) = 668.37$, $p < .001$ Effect size: *<0.2*, Partial $\eta^2 = .012$ Test used: *Post hoc* test using Bonferroni adjustment
80km/h rural	*M* =58.78 *SD* =9.85	*M* =57.93 *SD* =9.45	M =58.37 SD =10.59	Baseline $p < .001$	Baseline $p < .001$	Variable $p < .001$	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 816.97$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .94$ $F(1.89, 25088.32) = 72.67$, $p < .001$ Effect size: *<0.2*, Partial $\eta^2 = .005$ Test used: *Post hoc* test using Bonferroni adjustment
50km/h urban	*M* =45.54 *SD* =7.74	*M* =44.53 *SD* =7.16	M =44.59 SD =7.16	Baseline $p < .001$	Baseline $p < .001$	Fixed $p < .001$	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 138.93$, $p < .001$ Greenhouse-Geisser estimates of sphericity ($\varepsilon = .99$). $F(1.99, 108189.19) = 1158.52$, $p < .001$ Effect size: *<0.2*, Partial $\eta^2 = .021$ Test used: *Post hoc* test using Bonferroni adjustment

a) Table values for 'Results of statistical significance tests' show which ISA condition was significantly faster than the other.

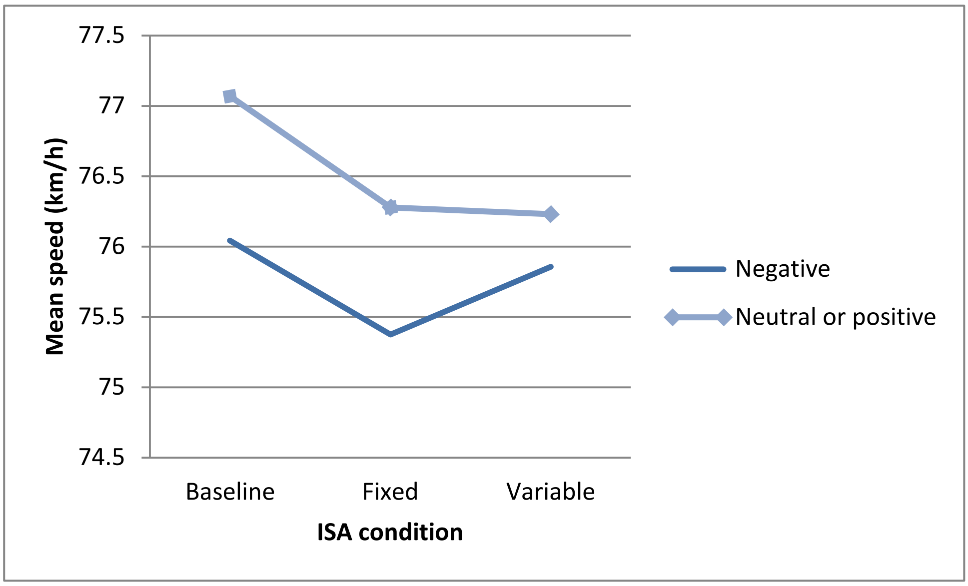
8.3.3 General attitudes to speeding

The participants were also divided into two groups based on their attitudes to speeding on the screening questionnaire scale. Items included positive and negative perceptions of exceeding the 100km/h speed limit on the motorway, such as whether this behaviour was perceived to be safe, enjoyable, harmful, useless, and so on. Those who overall believed speeding to be a negative thing to do were classed as having a negative attitude towards speeding, while those that were supportive of speeding behaviour were classed as having a positive attitude towards speeding.

A mixed-design ANOVA[33] was used to examine both between-groups ('Attitudes to speed' group) and repeated-measures (ISA condition) effects on speed. The ANOVA results revealed a significant interaction effect of attitudes to speed on ISA condition (F(1.98, 392863) = 168.98, p<.001, Partial η^2 = .001), with those with positive attitudes to speeding driving significantly faster in each ISA condition (see figure 8.13; p<.001).

Two repeated-measures one-way ANOVAs were performed for each 'Attitudes to speed' group to further examine the significant interaction effect, and both were found to be significant. Repeated-measures Bonferroni-corrected t-tests revealed that for both the positive- and negative-attitude groups, participants in both fixed and variable ISA conditions drove with significantly lower speeds than the baseline (p<.001). However, there was no difference between the fixed and variable ISA conditions for the positive-attitude group (p = .509), yet the negative-attitude group's speeds were significantly higher for the variable ISA condition when compared with the fixed ISA condition (p<.001).

Figure 8.13 ISA condition effects on mean speed, by 'Speed attitude' group



Overall, the findings were as follows:

- A significant interaction effect between attitudes to speed and ISA condition was found – those with positive attitudes towards speeding drove significantly faster in the fixed and variable ISA conditions than the baseline.

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[33] Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .99), after Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(2)$ = 1956.02, p< .001.

- Those with both positive and negative attitudes towards speeding had significantly faster speeds in the baseline compared with both the fixed and variable ISA conditions.
- The positive-attitude group showed no significant difference between the fixed and variable ISA conditions.
- The negative-attitude group had significantly higher speeds in the variable ISA condition than the fixed ISA condition.

8.3.4 Gender effects on ISA compliance

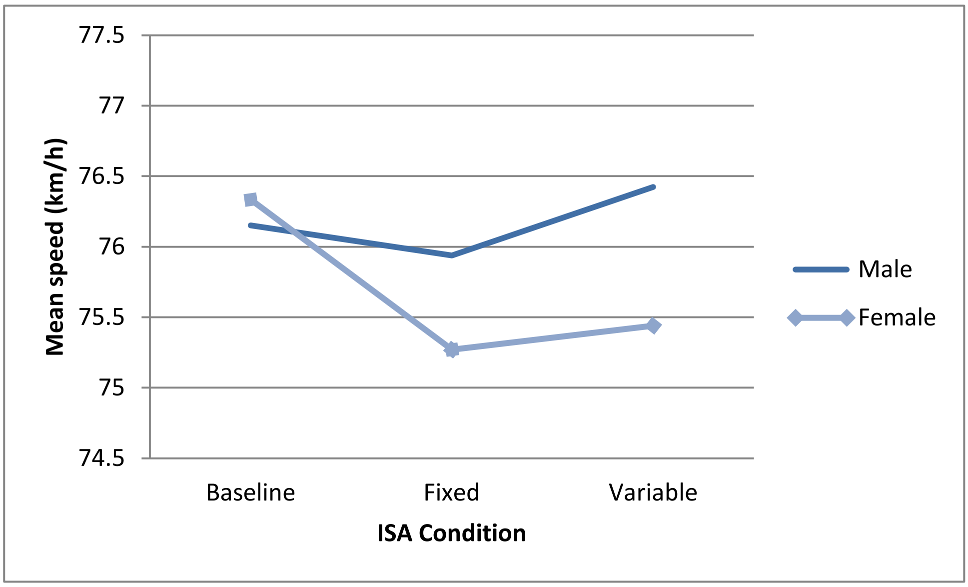
Across the entire route, there was a significant main effect of ISA condition on speed, whereby participants drove significantly more slowly in both the fixed ISA condition and variable ISA conditions, compared with the baseline condition ($F(2, 279014) = 48.34$, $p<.05$). Participants also drove significantly more slowly in the fixed ISA condition than the variable ISA condition. There was also a significant main effect of gender, with females driving significantly more slowly than males ($F(1, 279014) = 119.49$, $p<.05$). There was also a significant interaction effect between gender and ISA condition ($F(2, 279014) = 25.90$, $p<.05$). Simple effects analysis showed that females drove significantly more slowly than males in both the fixed and variable ISA conditions; however, there was no significant difference in speeds in the baseline condition.

A mixed-design ANOVA[34] was used to examine both between-groups (gender) and repeated-measures (ISA condition) effects on speed. The ANOVA results revealed a significant interaction effect of gender on ISA condition ($F(1.98, 414222.14) = 731.53$, $p<.001$, Partial $\eta^2 = .003$).These results suggest that there was greater compliance with both ISA conditions for female participants than male participants, which cannot be explained by this group generally driving more slowly than males, as there was no difference between genders in the baseline condition (see figure 8.14; p<.001).

Two repeated-measures one-way ANOVAs were performed for each gender group to further examine the significant interaction effect, and both were found to be significant. Repeated-measures Bonferroni-corrected t-tests revealed that for both females and males, there were similar (u-shaped) trends where baseline speeds were significantly higher than either ISA condition, and the variable ISA condition had significantly higher speeds than the fixed ISA condition (p<.001).

[34] Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(2) = 1985.83$, $p< .001$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .99$).

Figure 8.14 ISA condition effects on mean speed, by gender



Overall, the findings were as follows:

- A significant main effect of gender was found, with females driving significantly more slowly than males.
- There was also a significant interaction effect between gender and ISA condition. Females drove significantly more slowly in both the fixed and variable ISA conditions than males; however, there was no significant difference in speeds in the baseline condition, suggesting that ISA had a greater effect on compliance for females than males.
- For both females and males, baseline speeds were significantly higher than either the fixed or variable ISA condition; and the variable ISA condition had significantly higher speeds than the fixed ISA condition

8.3.5 Proportion of distance travelled over the speed limit

The proportion of distance drivers travelled relative to the speed limit was examined, based on the following categories of relative speed compliance: under the speed limit; between the speed limit and 3km/h over; between 3km/h and 8km/h over; and more than 8km/h over.[35] Figure 8.15 shows the relative speed compliance findings by ISA condition over the entire route and table 8.11 shows the findings by route section. This was analysed using a Friedman's ANOVA, with Wilcoxin *post hoc* tests.[36] Table 8.11 shows the proportion of trip length where variable ISA suggests that speeds were lower than the speed limit, by section.

[35] These categories were based on the ISA stimulus feedback thresholds, where drivers received increasing levels of audio-visual feedback with incrementing categories.

[36] Wilcoxin tests were used to examine *post hoc* differences with a Bonferroni adjustment applied, so all effects are reported at a .0167 level of significance.

Figure 8.15 Percentage of distance travelled over the route, by relative level of speed limit compliance and ISA condition

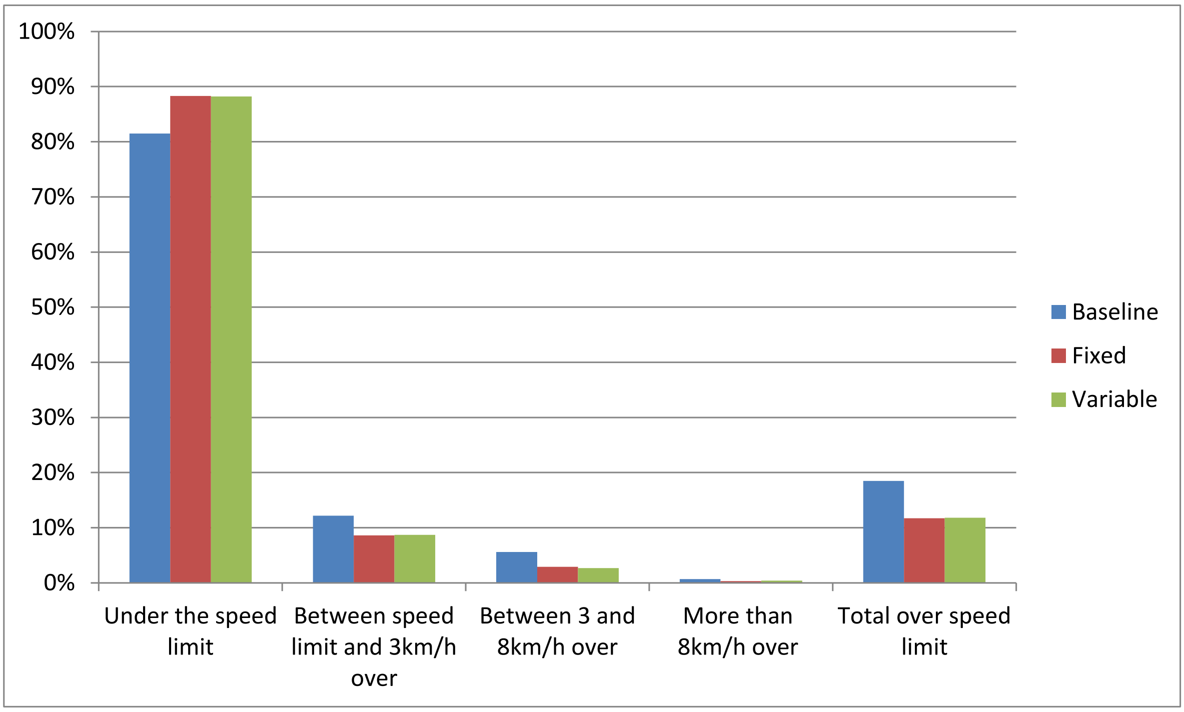


Table 8.11 Percentage of distance travelled, by relative level of speed limit compliance, by route section and ISA condition

Route section	Speed compliance relative to the speed limit	ISA condition		
		Baseline	Fixed	Variable
Overall	Under the speed limit	81.5%	88.3%	88.2%
	Between speed limit and 3km/h over	12.2%	8.6%	8.7%
	Between 3 and 8km/h over	5.6%	2.9%	2.7%
	More than 8km/h over	0.7%	0.3%	0.4%
	Total over speed limit	18.5%	11.7%	11.8%
100km/h multilane	Under the speed limit	74.1%	84.2%	84.5%
	Between speed limit and 3km/h over	17.3%	11.8%	11.7%
	Between 3 and 8km/h over	8.3%	4.0%	3.6%
	More than 8km/h over	0.2%	0.0%	0.1%
	Total over speed limit	25.9%	15.8%	15.5%
100km/h rural single lane	Under the speed limit	98.4%	98.5%	98.1%
	Between speed limit and 3km/h over	1.5%	1.3%	1.6%
	Between 3 and 8km/h over	0.1%	0.3%	0.3%
	More than 8km/h over	0.0%	0.0%	0.0%
	Total over speed limit	1.6%	1.5%	1.9%
80km/h rural	Under the speed limit	99.4%	99.5%	98.6%
	Between speed limit and 3km/h over	0.3%	0.5%	1.1%
	Between 3 and 8km/h over	0.3%	0.0%	0.4%
	More than 8km/h over	0.0%	0.0%	0.0%
	Total over speed limit	0.6%	0.5%	1.4%

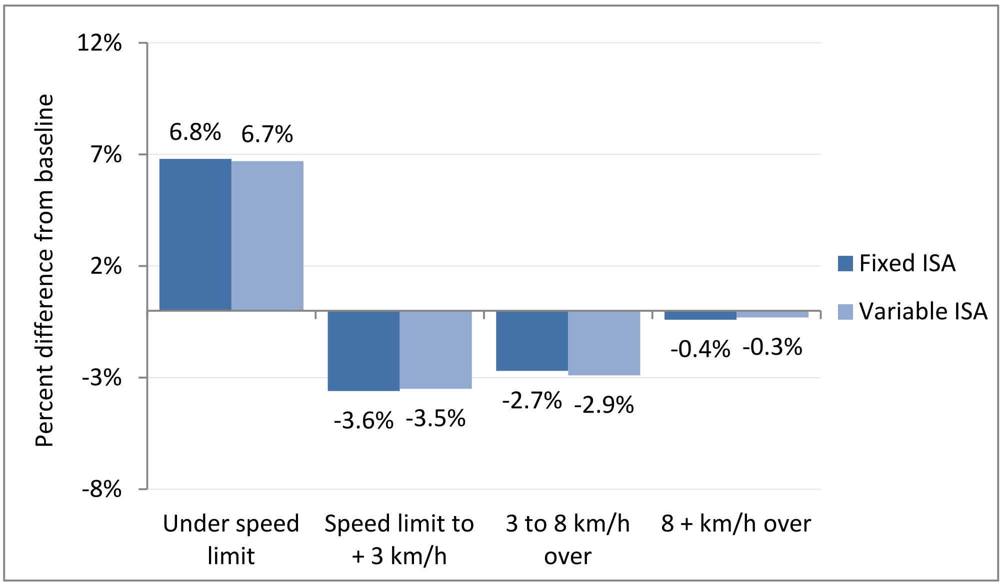
Route section	Speed compliance relative to the speed limit	ISA condition		
		Baseline	Fixed	Variable
50km/h	Under the speed limit	71.8%	83.5%	82.5%
	Between speed limit and 3km/h over	17.8%	12.1%	13.1%
	Between 3 and 8km/h over	8.9%	3.7%	3.5%
	More than 8km/h over	1.5%	0.7%	0.9%
	Total over speed limit	28.2%	16.5%	17.5%

Because of the repeated-measures approach, the findings were reported on the baseline condition, so the implication for this study was that the differences from the baseline were more constrained than in a non-experimental condition. In other words, any findings here were likely to be conservative.

Figures showing speed compliance for each ISA condition for the whole route and for each road section type are shown below, and table 8.12 summarises the results of the effects of ISA on speed compliance. In each case, *post hoc* tests were used.

Overall speed compliance, by condition, can be seen in figure 8.16, which shows the percentage difference from the baseline condition in proportion of distance travelled. Over the entire route distance, the participants' level of speed compliance did vary by ISA condition, and *post hoc* tests revealed that participants were significantly more likely to drive at or under the speed limit in both the fixed ISA and the variable ISA conditions compared with the baseline. However, there was no difference between the fixed and variable ISA conditions.

Figure 8.16 Percentage difference from baseline in proportion of distance driven, by level of speed limit compliance for fixed and variable ISA conditions, for the overall route



Figures 8.17–8.21 show the speed compliance, by ISA condition, for each road section.

Figure 8.17 Percentage difference from baseline in proportion of distance driven, by level of speed limit compliance for fixed and variable ISA conditions, for 100km/h rural multilane roads

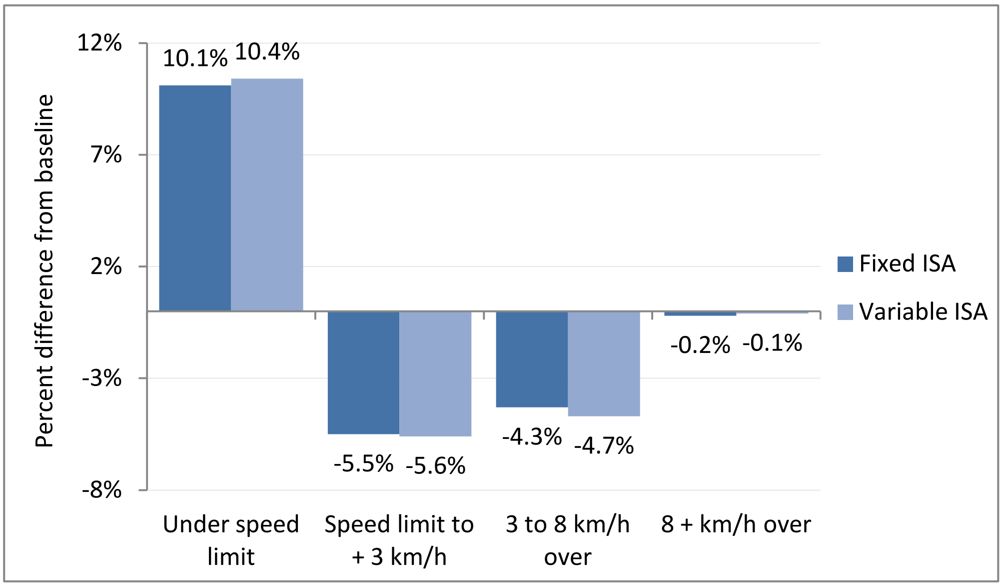


Figure 8.18 Percentage difference from baseline in proportion of distance driven, by level of speed limit compliance for fixed and variable ISA conditions, for 100km/h rural single-lane carriageway roads

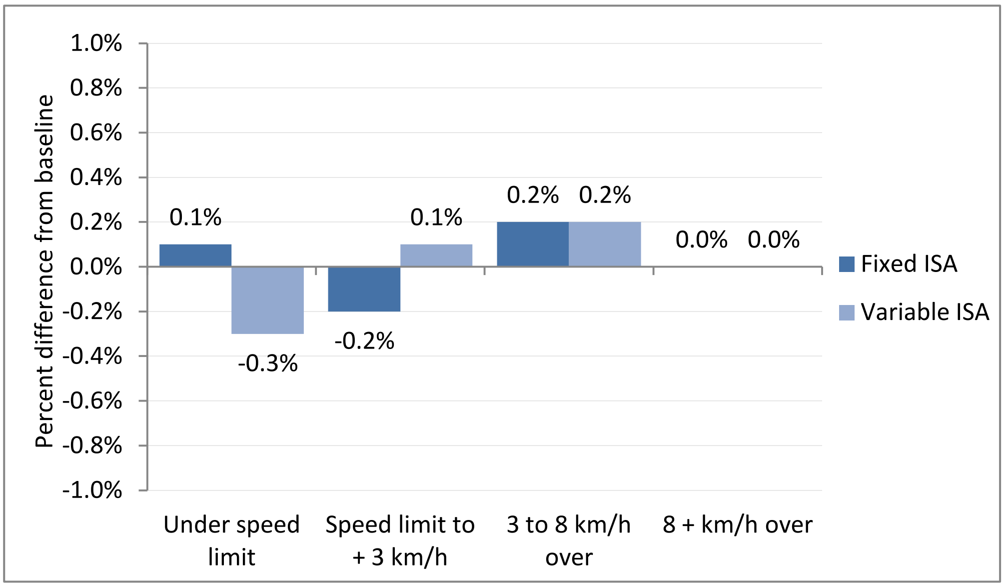


Figure 8.19 Percentage difference from baseline in proportion of distance driven, by level of curve advisory speed compliance for fixed and variable ISA conditions, for rural single-lane carriageway roads

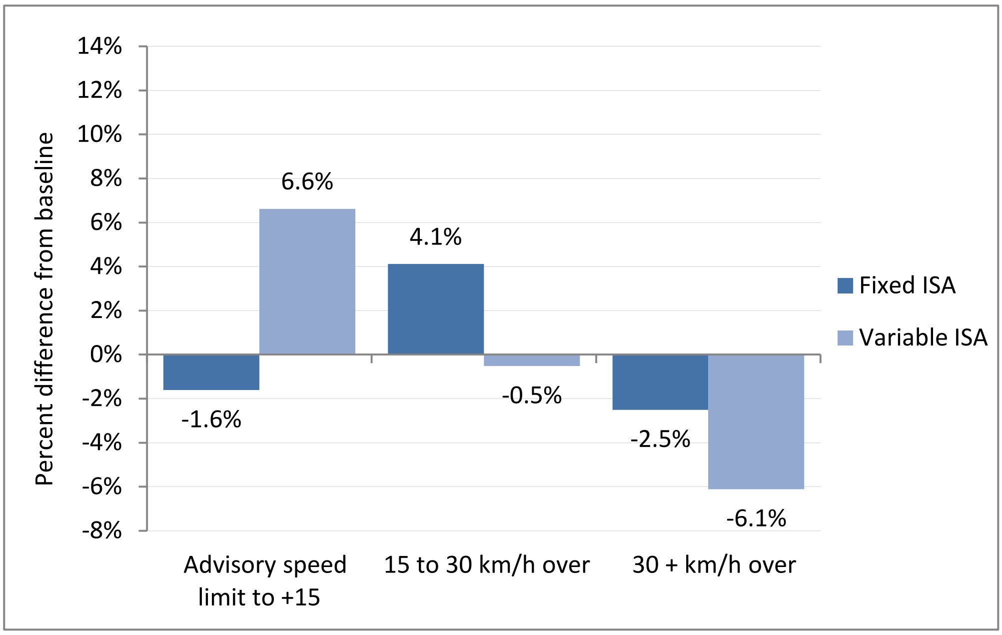


Figure 8.20 Percentage difference from baseline in proportion of distance driven, by level of speed limit compliance for fixed and variable ISA conditions, for 80km/h rural (single-lane carriageway) roads

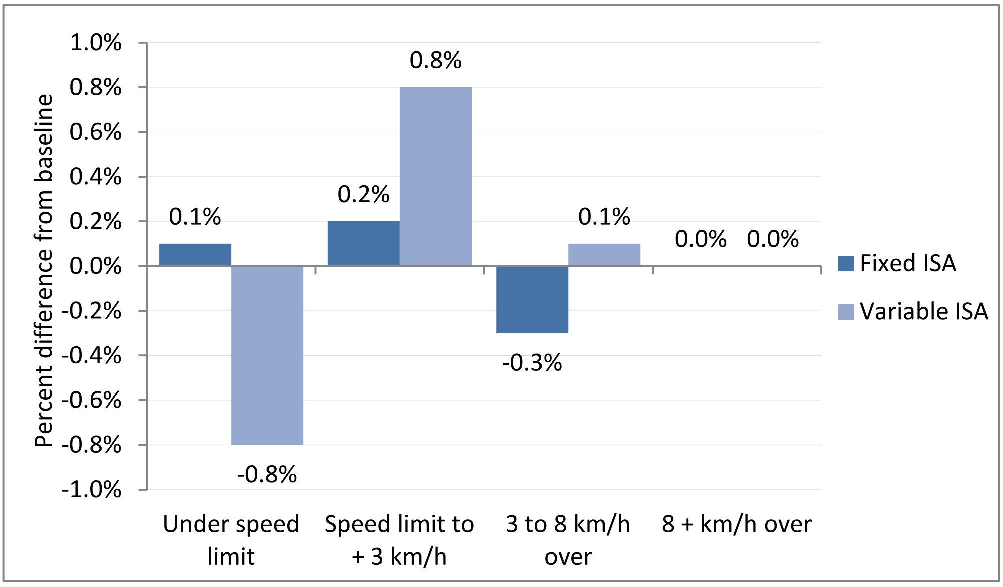
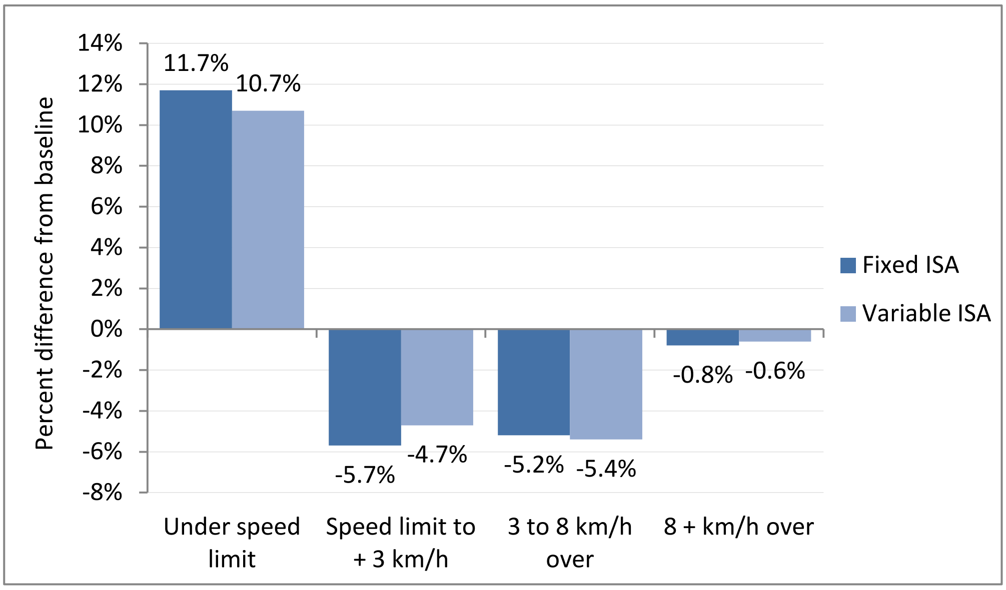


Figure 8.21 Percentage difference from baseline in proportion of distance driven, by level of speed limit compliance for fixed and variable ISA conditions, for 50km/h urban roads



Overall, for each road section type in figures 8.17–8.21 and table 8.12, with the exception of the 100km/h rural single-lane carriageway, the difference in the level of speed compliance between ISA conditions was significant. Table 8.12 shows that with the exception of the 100km/h rural single-lane carriageway section, participants under the fixed and variable ISA conditions were significantly more likely to drive under the speed limit than under the baseline condition. However, there was more variation between the fixed and variable ISA conditions. For 100km/h rural multilane roads, participants were significantly more likely to drive under the speed limit under the variable ISA condition than when under the fixed ISA condition. The opposite was true in 50km urban sections. In the 80km/h sections and over the trial route, there was no significant difference between the fixed and variable ISA conditions (generally consistent with results by Fildes et al 1987 and 1989).

For the 100km/h rural single-lane carriageway, which showed that the difference in the level of speed compliance between ISA conditions was not significant, an additional analysis was undertaken to determine the effect of curve advisory warnings. Categories of relative advisory curve speed compliance were developed following a similar method to that used for speed limit compliance. The categories included: under the advisory curve speed; between the advisory curve speed and 15km/h over; between 15km/h and 30km/h over; and more than 30km/h over.[37] This analysis found that the difference in the level ofadvisory curve compliance between ISA conditions was significant and that under the variable ISA condition, participants were significantly more likely to drive under the advisory curve speed than when under either the fixed ISA condition or the baseline condition. Unsurprisingly (as no advisory information was provided to either of these groups), there was no significant difference between the fixed ISA and the baseline.

[37] These categories were based on the ISA stimulus feedback thresholds, where drivers received increasing levels of audio-visual feedback with incrementing categories.

Table 8.12 Effects on speed compliance, by ISA condition and road section[a]

Route section, by speed zone and road type	Significance of level of speed compliance between ISA condition	Results of statistical significance tests (using *post hoc* tests)		
		Fixed v baseline ISA	Variable v baseline ISA	Fixed ISA in relation to variable ISA
Speed limit compliance				
Overall trial route	Significant X^2(2, *N* = 208106) = 11298.35, *p*<.05	Fixed T = 236860895, r = -0.193	Variable T = 242416871, r = -0.188	No significant difference T = 272142256.5, r = -0.005
100km/h rural single-lane carriageway	Not significant X^2 (2, *N* = 35160) = 3.27, p >.05	No significant difference	No significant difference	No significant difference
100km/h rural multilane (expressway & motorway)	Significant X^2(2, *N* = 55694) = 5575.01, *p*<.05	Fixed T = 26765643, r = -0.260	Variable T = 28218523.5, r = -0.257	Variable T = 31952879.50, r = -0.011
80km/h rural single-lane carriageway	Significant X^2(2, *N* = 13293) = 94.160, *p*<.05	Fixed T = 3172, r = -0.031	Variable T = 8629, r = -0.051	No significant difference T = 6466, r = -0.079
50km/h urban	Significant X^2(2, *N* = 53830) = 5449.370, *p*<.05	Fixed T = 29636873.5, r = -0.263	Variable T = 32168520, r = -0.245	Fixed T = 38082600, r = -0.027
Advisory curve speed compliance				
100km/h rural single-lane carriageway	Significant X^2(2, *N* = 3917) = 251.85, *p*<.05	No significant difference T = 531332.5, r = -0.012	Variable T = 203784, r = -0.248	Variable T = 329604.00, r = -0.193

a) Table cells for 'Results of statistical significance tests' show under which ISA condition participants were significantly more likely to drive under the speed limit or advisory curve speed.

8.3.6 Effects of ISA at selected curves

8.3.6.1 Crash analysis of curves

A crash analysis of the advisory speed curves on the rural sections of the trial route was undertaken to identify the most high-risk curves. An analysis of 2006–2010 run-off-road, speed-related, and total-injury crashes was used to identify three curves to analyse in detail (presented in table 8.13). As the four top-ranked curves all had low advisory speeds, the highest-ranked 75km/h advisory curve (curve rank number 5) was chosen as the third curve to study, to get a range of curve features.

Table 8.13 Injury crashes on SH58 advisory speed curves, 2006–2010[a]

Curve rank	Start displacement (m)[b]	End displacement (m)[a]	Speed limit (km/h)	Advisory speed (km/h)	Injury crashes	Run-off-road injury crashes	Speed-related injury crashes
1	**11,460**	**11,720**	**80**	**45**	**19**	**14**	**7**
2	**12,730**	**12,990**	**80**	**35**	**10**	**4**	**5**
3	12,480	12,730	80	45	8	6	4
4	12,270	12,410	80	35	7	4	2
5	**1840**	**2070**	**100**	**75**	**6**	**5**	**3**
6	610	860	100	75	3	2	1

a) This analysis used the start and end points of consecutive Out-of-Context Curves; however, if the 100m after the end of the advisory zone is also included, the ranking of the curves is the same. The start and end displacement refer to the distance from the start of SH58.

b) Displacement relative to the start of SH58 at SH2. Note: Selected curves in bold, with light shading.

The curve with rank number 1 (curve 1) has a hazard advisory warning of 45km/h and is positioned on an 80km/h rural road. According to crash statistics from 2006 to 2010, this curve had 19 injury crashes during that period, 14 of which were ‘run-off-road’ and 7 were judged to have involved speed. The average, minimum and maximum speeds are presented in figure 8.22, based on the 80m prior to the curve advisory zone (pre), the area of the curve advisory zone (during) and the 80m after the curve advisory zone (post). This analysis was repeated for curve rank numbers 2 and 5 (curve 2 and 5), and the results are plotted in figures 8.23 and 8.24.

Figure 8.22 Mean, minimum and maximum speeds at curve 1, by ISA condition

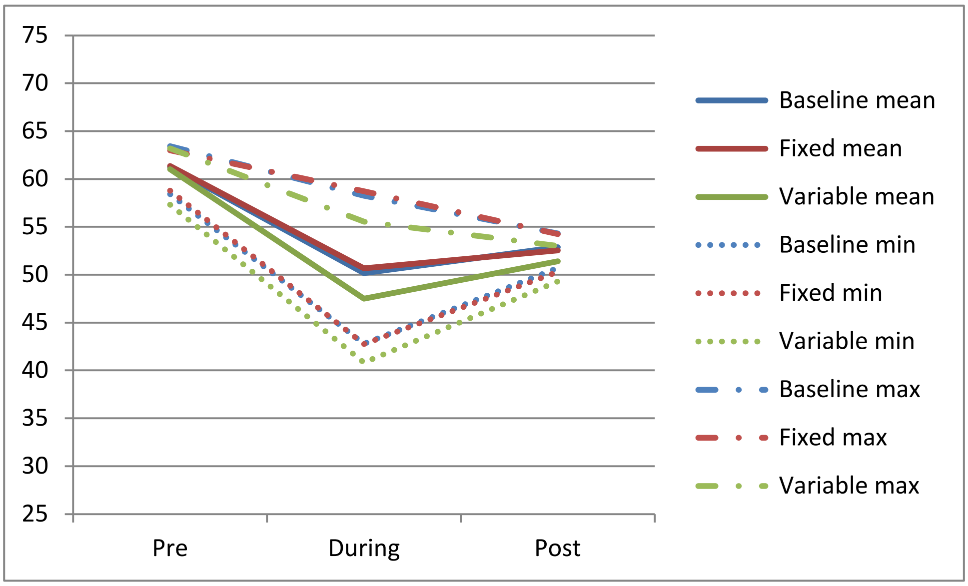
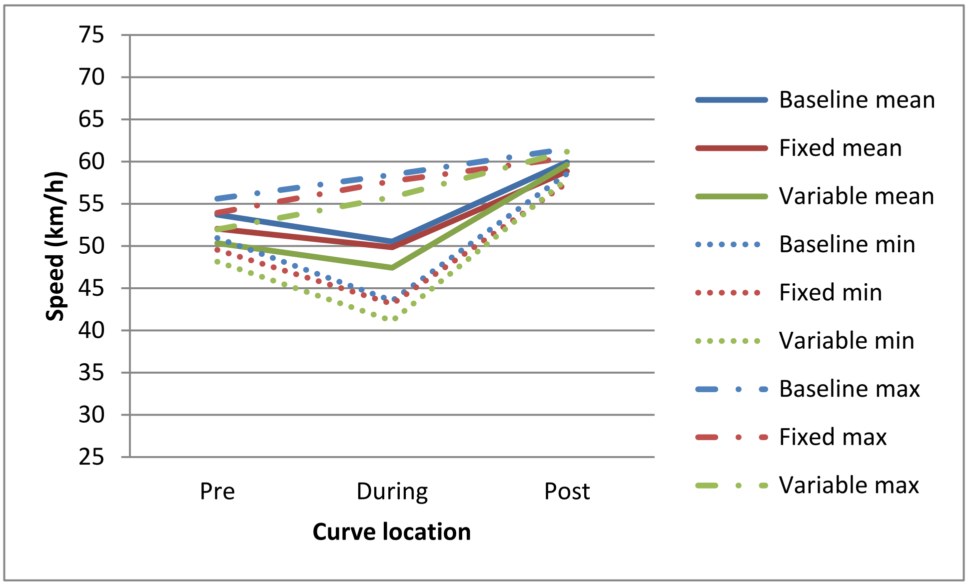
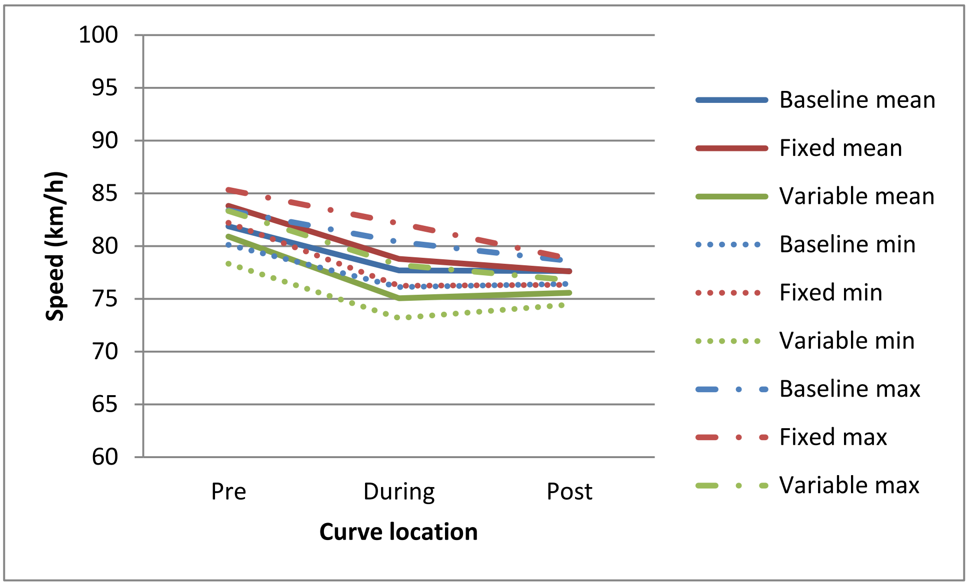


Figure 8.23 Mean, minimum and maximum speeds at curve 2, by ISA condition



Curve 2 has a 45km/h advisory curve immediately preceding it, which explains the low speeds prior to the curve.

Figure 8.24 Mean, minimum and maximum speeds at curve 5, by ISA condition



A summary of the curve analysis findings is shown in tables 8.14–8.16 and (by curve) in table 8.17, and indicates that variable ISA was consistently effective at reducing mean curve speeds, and generally effective at reducing curve entry and exit speeds – baseline and fixed ISA speeds were significantly faster than variable ISA in all cases where there was a statistically significant difference between them.

The difference between baseline and fixed ISA was variable. In some cases there was no significant difference (exits speeds on all three curves, curve 1 entry and mean speeds); in others, the baseline was significantly faster than the fixed ISA, and vice versa.

Table 8.14 Effects on mean curve speed, by ISA condition and road section[a]

Curve rank	Mean curve speed, M; & standard deviation, SD (km/h)			Results of statistical significance tests (using *post hoc* tests)			Statistical test details
	Baseline	Fixed ISA	Variable ISA	Fixed ISAv baseline	Variable ISA v baseline	Fixed v variable ISA	
1	*M* =50.17 *SD* =7.57	*M* =50.66 *SD* =7.69	*M* =47.50 *SD* =6.59	No significant difference $p = .34$	Baseline $p < .001$	Fixed $p < .001$	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 195.31$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .84$ $F(1.68, 1527.05) = 81.68$, $p < .001$ Effect size: *<0.2,* (Partial $\eta^2 = .082$) Test used: *Post hoc* test using Bonferroni adjustment
2	*M* =50.54 *SD* =6.85	*M* =49.83 *SD* =6.15	*M* =47.42 *SD* =6.74	Baseline $p < .05$	Baseline $p < .001$	Fixed $p < .001$	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 15.87$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .98$ $F(1.97, 1942.99) = 100.36$, $p < .001$ Effect size: *<0.2,* (Partial $\eta^2 = .092$) Test used: *Post hoc* test using Bonferroni adjustment
5	*M* =77.67 *SD* =9.52	*M* =78.77 *SD* =9.46	*M* =75.06 *SD* =8.94	Fixed $p < .05$	Baseline $p < .001$	Fixed $p < .001$	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 49.20$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .94$ $F(1.88, 1390.44) = 90.35$, $p < .001$ Effect size: *<0.2,* (Partial $\eta^2 = .109$) Test used: *Post hoc* test using Bonferroni adjustment

a) Table cells for 'Results of statistical significance tests' show under which ISA conditions participants drove significantly faster.

Table 8.15 Effects on curve entry speed, by ISA condition and road section[a]

Curve rank	Mean curve entry speed, M; & standard deviation, SD (km/h)			Results of statistical significance tests (using *post hoc* tests)			Statistical test details
	Baseline	Fixed ISA	Variable ISA	Fixed ISA v baseline	Variable ISA v baseline	Fixed v variable ISA	
1	Not reported	Not reported	Not reported	No significant difference	No significant difference	No significant difference	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 17.18$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .95$ Curve entry speed was *not* significant between ISA conditions ($p = .78$)
2	*M* =53.53 *SD* =6.85	*M* =52.89 *SD* =6.34	*M* =51.65 *SD* =6.63	Baseline $p < .001$	Baseline $p < .001$	Fixed $p < .001$	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 276.59$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .94$ $F(1.88, 7689.75) = 122.79$, $p < .001$ Effect size: *<0.2,* (Partial $\eta^2 = .029$) Test used: *Post hoc* test using Bonferroni adjustment
5	*M* =81.88 *SD* =9.24	*M* =83.82 *SD* =9.26	*M* =75.99 *SD* =22.46	Fixed $p < .001$	No significant difference $p = .07$	Fixed $p < .001$	One-way repeated-measures ANOVA $F(2, 622) = 22.52$, $p < .001$ Effect size: *<0.2,* (Partial $\eta^2 = .068$) Test used: *Post hoc* test using Bonferroni adjustment

a) Table cells for 'Results of statistical significance tests' show under which ISA conditions participants drove significantly faster.

Table 8.16 Effects on curve exit speed, by ISA condition and road section[a]

Curve rank	Mean curve exit speed, M; & standard deviation, SD (km/h)			Results of statistical significance tests (using *post hoc* tests)			Statistical test details
	Baseline	Fixed ISA	Variable ISA	Fixed ISA v baseline	Variable ISA v baseline	Fixed v variable ISA	
1	*M* =52.86 *SD* =7.11	*M* =52.53 *SD* =5.43	*M* =75.99 *SD* =22.46	No significant difference $p = 1.0$	Baseline $p < .001$	Fixed $p < .001$	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 118.36$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .76$ $F(1.51, 457.62) = 5.09$, $p < .05$ Effect size: *<0.2*, (Partial $\eta^2 = .017$) Test used: *Post hoc* test using Bonferroni adjustment
2	Not reported	Not reported	Not reported	No significant difference	No significant difference	No significant difference	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 20.17$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .94$ $F(1.88, 569.22) = 3.13$, $p < .05$ Effect size: *<0.2*, (Partial $\eta^2 = .010$) Test used: *Post hoc* using Bonferroni adjustment Curve exit speeds were *not* significant between ISA conditions
5	*M* = 77.64 *SD* = 9.41	*M* = 77.59 *SD* = 9.33	*M = 75.57 SD = 8.12*	No significant difference $p = 1.0$	Baseline $p < .001$	Fixed $p < .001$	One-way repeated-measures ANOVA Mauchly's test result: $\chi^2(2) = 87.15$, $p < .001$ Greenhouse-Geisser estimates of sphericity: $\varepsilon = .80$ $F(1.61, 499.57) = 13.02$, $p < .001$ Effect size: *<0.2*, (Partial $\eta^2 = .04$) Test used: *Post hoc* using Bonferroni adjustment

a) Table cells for 'Results of statistical significance tests' show under which ISA conditions participants drove significantly faster.

Table 8.17 Effect of speed compliance, by ISA condition on the respective curves chosen for study[a]

Curve rank number	Curve entry speeds			Curve speeds			Curve exit speeds		
	Fixed ISA v baseline	Variable ISA v baseline	Fixed v variable ISA	Fixed ISA v baseline	Variable ISA v baseline	Fixed v variable ISA	Fixed ISA v baseline	Variable ISA v baseline	Fixed v variable ISA
Curve 1	No diff[b]	No diff	No diff	No diff	Baseline	Fixed	No diff	Baseline	Fixed
Curve 2	Baseline	Baseline	Fixed	Baseline	Baseline	Fixed	No diff	No diff	No diff
Curve 5	Fixed	No diff	Fixed	Fixed	Baseline	Fixed	No diff	Baseline	Fixed

a) Table cells show under which ISA condition participants drove significantly faster.

b) 'No diff' indicates no significant difference between ISA conditions.

8.3.7 Questionnaire findings

8.3.7.1 Attitudes towards ISA

Table 8.18 displays summary statistics for three 'Attitudes to ISA scales' that were formed from the questionnaire items. This scale included 12 items examining potentially negative (eg frustration and distraction) and positive (eg better speed information, safer driving behaviour) effects of ISA when compared with driving in normal, non-ISA conditions. As higher scores indicate more positive attitudes towards ISA, participants were least in favour of the technology after experiencing the variable ISA condition.

Table 8.18 'Attitudes towards ISA scale' summary statistics[a]

Scale	No. of scale items	Number of participant responses, N=40)	Mean	Min.	Max.	Std. deviation	Cronbach's alpha (α)
Pre-ISA scale	12	38	43.2	29	53	4.9	.79
Fixed ISA scale	12	39	44.0	26	52	6.2	.84
Variable ISA scale	12	39	40.9	29	52	6.2	.84

a) The scale was made up of 12 items, with each item scored on a 1–5 Likert scale, so the midpoint of the scale was 36, with a possible range from 12 to 60.

A one-way repeated-measures ANOVA was used to assess differences in attitudes towards ISA before and after exposure to the ISA conditions. The results show attitudes differed significantly between conditions (F(2, 70) = 9.28, p<.001, Partial η^2 = .21).

Paired samples t-tests revealed a negative exposure effect with the variable ISA condition. Those who had just experienced the variable ISA condition scored significantly lower (indicating more negative attitudes towards ISA) than before they used any ISA device (t(36) = 3.08, p<.01). In addition, participants had more negative attitudes towards ISA after completing the route with the variable ISA condition than after completing the route with the fixed (t(37) = 3.9, p<.001). There were no significant differences in attitudes between the pre and fixed ISA condition (t(36) = -.682, p = .50), meaning that attitudes towards ISA were not affected by the experience of the fixed ISA condition.

No significant order effects were observed in these relationships, with those who started with the fixed ISA versus variable ISA condition having no differences on means for either attitudes towards fixed ISA (t(18.65) = -1.86, p = .08) or variable ISA (t(25) = -1.81, p = .08). Therefore, the order in which participants experienced the ISA conditions did not explain the observed differences.

No gender differences were found for scores on the 'Attitudes to ISA' scale before experiencing any ISA condition (t(36) = .12, p = .91), after the fixed ISA condition (t(37) = -0.30, p = .98) or after the variable ISA condition (t(37) = -0.74, p = .47).

In addition, no significant relationships were found between age group and score on the scale before experiencing any ISA condition (r(36) = -.01, p > .05), after the fixed ISA condition (r(37) = -.12, p > .05) or after the variable ISA condition (r(37) = .01, p > .05). This also held true when exploring the effects of driving experience on pre-ISA (r(30) = .02, p > .05),fixed ISA (r(32) = -.11, p > .05) or variable ISA (r(31) = -.11, p > .05) scales' scores.

Overall, there was no evidence that demographics were related to scores on the 'Attitudes to ISA' scales.

8.3.7.2 Self-reported effects on driving

Item means for self-reported effects on driving under the fixed and variable ISA conditions are reported in table 8.19, with higher scores on the Likert 1–5 scale indicating the participants believed the ISA system had a larger effect on the area listed (from 'decreased the behaviour significantly' to 'increased the behaviour significantly', with a score of three being neutral).

Table 8.19 Self-reported ISA system effects on driving (number of participant responses, N=40)[a]

	Fixed ISA condition		Variable ISA condition	
	Mean	SD	Mean	SD
Travel time	3.0	.75	3.1	.81
Probability of being fined	1.9	.73	2.1	.60
Attentiveness to traffic	3.3	.79	3.3	.76
Following distances	3.2	.53	3.2	.46
Ease of overtaking	2.5	.82	2.5	.78
Tendency to obey speed limits	4.1	.65	4.2	.62
Fuel consumption	3.0	.53	2.9	.53
Comfort of the driving task	2.9	.81	2.6	.75
Enjoyment of the driving task	2.8	.90	2.6	.82
Ability to avoid dangerous situations	3.3	.55	3.0	.66

a) Scale ranges from 1 to 5; 3 = Neutral; large scores indicate a large effect.

Paired samples t tests were used to explore differences in item means between ISA conditions. Only two items had significantly different means between the two ISA conditions; 'comfort of the driving task' ($r(32) = -.11$, $p > .05$) and 'ability to avoid dangerous situations'($r(31) = -.11$, $p > .05$).

Both ISA conditions were perceived to decrease the comfort of the driving task to some degree. However, those who had just completed the variable ISA condition rated a higher negative effect on comfort from the ISA device than those who had just completed the fixed ISA condition. In relation to participants' ability to avoid dangerous situations, the fixed ISA condition was perceived to slightly increase this ability on average, whereas the variable ISA condition was perceived to have little or no effect.

Comments made by participants regarding why they would not use the ISA system offered some explanation for this second finding, with a number of participants stating they felt the variable ISA system could have made them a hazard due to their slow speeds. Some of these participants reported creating a line of cars behind them, which was similar to findings from other reported ISA trials (eg Comte 2000).

8.3.7.3 HMI features

Table 8.20 displays item means for questions relating to the HMI features of the ISA devices (with higher means indicating a higher level of agreement with the item).

Table 8.20 Summary statistics for HMI features (number of participant responses, N=40)

	Fixed ISA condition		Variable ISA condition	
	Mean	Std. dev.	Mean	Std. dev.
System easy to use	4.2	.69	4.1	.53
Visual warnings easy to understand	4.4	.63	4.2	.55
Visual warnings not irritating	3.9	.81	3.4	1.1
Auditory warnings easy to understand	4.1	.78	3.8	.96
Auditory warnings not irritating	3.1	1.2	2.8	1.3
Auditory warnings easy to hear	4.0	.75	3.9	.71
Received enough warning of upcoming speed limit changes	4.1	.79	4.0	.89
Received enough warning of upcoming hazard advisories[a]	-	-	3.2	1.1

a) This question only related to the variable ISA system so was not asked in relation to the fixed ISA condition. N=39 for this item.

Participants found both ISA conditions easy to use and understand, and felt they received enough warning of speed limit changes. They generally found the auditory warnings more irritating than the visual warnings, but neither was rated as highly irritating.

Cronbach's alphas were not high enough to create scales from the items displayed in the table above, so paired-samples t-tests were used to assess whether there were any differences on individual item means between ISA conditions. The only significant difference found was in relation to the visual feedback provided from the two conditions. In summary:

- Participants who had just experienced the fixed ISA condition agreed more strongly that the visual warnings were easy to understand than those who had just experienced the variable ISA condition ($t(39) = 2.97$, $p<.01$).
- Participants who had just experienced the variable ISA condition agreed more strongly that the visual warnings were irritating than those who had just experienced the fixed ISA condition ($t(39) = 2.57$, $p<.05$).

These findings fit with previous findings showing that attitudes towards the fixed ISA condition were overall more positive than those towards the variable ISA condition.

8.3.7.4 Anticipated future usage

The proportions of participants who reported they would or wouldn't use the fixed and variable ISA systems in the future (if it was standard equipment) are reported in table 8.21. As can be seen, the majority of participants reported they would use both the fixed and variable ISA systems in the future if they were made available and/or had some design changes.

Table 8.21 Anticipated future use of fixed and variable ISA

	Fixed ISA condition	Variable ISA condition
Would use with no design changes	12 (30.0%)	4 (10.0%)
Would use with some design changes	26 (65.0%)	31 (77.5%)
Would not use	2 (5.0%)	5 (12.5%)
Total	**40 (100.0%)**	**40 (100.0%)**

Where participants stated they would use either ISA condition with design changes, they were asked to suggest alterations to improve the technology's attractiveness. In line with this, where participants stated they would not use either ISA condition in the future, they were asked for reasons for this decision. Summaries of the answers to these qualitative questions are provided below.

Suggestions for fixed ISA design changes:

- Make it more customisable (N=11) eg:
    - make it possible to change the volume of the auditory warnings (including being able to turn them off completely) (N=4)
    - provide auditory feedback options, including having an oral feedback option so drivers could better understand the auditory warnings (N=4)
    - make the display brightness adjustable for driving at night (N=2)
    - make it possible to adjust the speed at which the device beeps (N=1).
- Remove the auditory warning for upcoming speed limit changes, or make these come on closer to the speed limit change sign (especially for speed limit increases) – however, one participant believed more distance was needed for speed limit decreases (N=4).
- Change the visual feedback provided (eg make the speed limit flash when the driver is speeding; have a yellow indicator when only 5km/h over the speed limit) (N=2).
- Add the vehicle's actual speed to the device (to remove the need to look at both the vehicle's speedometer and the device) (N=4).
- Improve the accuracy of the device (eg the accuracy of measurement of the vehicle's speed) (N=1).
- Ensure it is possible to turn the device off (particularly for roads the driver is familiar with) (N=3).
- Improve the quality of the graphics displayed (N=1).
- Increase the leeway provided before warnings are given (especially around features such as on- and off-ramps, and take into consideration overtaking manoeuvres) (N=1).
- Integrate ISA with traditional GPS mapping systems and other information (eg weather, road layout, speed cameras) (N=2).
- Make ISA a part of the vehicle itself (eg integrated with the speedometer itself) (N=1).

Suggestions for variable ISA design changes:

- Make it more customisable (N=28) eg:
    - make it possible to adjust the speeds at which it beeps (N=5)

- make it possible to adjust when information is provided before curves, advisories and speed limit changes (some participants believed the information was provided too abruptly, while others believed they came on too early and stayed on too long) (N=6)
- make the display brightness adjustable for night-time driving (N=1)
- make it possible to turn off the advisory feedback (N=3)
- make it possible to change the volume of the auditory warnings (including being able to turn off the auditory warnings altogether) – one participant stated the visual warnings were more effective (N=12)
- provide auditory feedback options (eg adjustable alarms), including an oral feedback option so drivers can better understand the auditory warnings (N=3)
- ensure it is possible to turn the device off (particularly for roads the driver is familiar with) (N=3).

• Add the car's actual speed to the device (to remove the need to look at both the vehicle's speedometer and the device) (N=4).
• Improve the quality of the graphics displayed (N=2).
• Integrate more information into the ISA system (however, no specific suggestions on what information to integrate were offered) (N=1).
• Add a visual warning for when the driver is going well under the speed limit (eg 25% under) (N=1).
• Change the visual feedback provided (eg have a yellow indicator when just over the speed limit) (N=1).
• Increase the leeway provided before warnings are given (to reduce problems with holding up other traffic) (N=3).
• Make the device smaller (N=1).
• Have the speed limit of the area displayed at all times (N=1).

Reasons given for not wanting to use fixed ISA in the future:

The two participants who stated they would not use the fixed ISA system listed a number of reasons for this, including: the auditory warnings were annoying and pointless; feedback information was inaccurate in some instances; and the system was too 'touchy' and distracting.

Reasons given for not wanting to use variable ISA in the future:

The five participants who stated they would not use the variable ISA system listed the following reasons: it would make driving less enjoyable and more frustrating; curve advisories seemed inaccurate and were activated too soon before curves and too long after; the auditory warnings were too annoying and some felt it made them a nuisance and a hazard on the road (causing them to slow down and speed up often, and create a train of cars behind them).

Clearly some of the reasons given for not wanting the use the fixed and variable ISA systems would be improved by attending to the suggested changes given by other participants.

Demographics and anticipated future usage:

Gender and age did not have a significant impact on anticipated future use of either the fixed ($p = .37$ and $p = .60$, respectively)[38] or variable ($p = .15$ and $p = .57$, respectively) ISA systems. Driving experience was not related to anticipated future use of the variable ISA system ($p = .95$), but was significantly related to anticipated future use of the fixed ISA system ($p<.05$). Pearson's r shows that there is a moderate, negative relationship between driving experience and anticipated future use ($r(32) = -0.38$, $p<.05$), meaning that those with greater driving experience were more likely to agree they would use the system if changes were made, or reported they would not use the system at all.

8.3.7.5 Other hazards to include in future ISA technology

Trial participants were asked which other hazardous road conditions should be integrated into any future versions of the ISA device. The results are displayed in table 8.22 (ordered by the most frequently endorsed hazardous condition). As can be seen, nearly all the participants believed school zones should be targeted in any future ISA devices, with around 70% believing both temporary speed zones and railway crossings should also be added. Those who endorsed the 'other' option listed the following hazardous situations:

- pedestrian crossings (N=3)
- hazard sites (N=1)
- 'slippery when wet' areas (N=1)
- major intersections (eg on 100km/h roads) (N=1)
- passing lanes (N=1)
- real-time hazards (eg flooding) (N=1).

Table 8.22 Summary statistics for future hazard integrating[a]

	Frequency
School zones	37 (92.5%)
Temporary speed zones	28 (70.0%)
Railway crossings	27 (67.5%)
Curves without advisories	12 (30.0%)
Other	7 (17.5%)
Bus stops	5 (12.5%)
Shopping areas	0 (0.0%)
None of these	0 (0.0%)
Total	**40**

a) Participants could select multiple items, so percentages do not add to 100%.

8.3.7.6 Groups that would benefit from ISA

Trial participants were asked which groups would benefit most from having some form of ISA in their vehicle. The results are displayed in table 8.23 (ordered by the most frequently endorsed group). As can be seen, novice and young drivers were the most-endorsed groups, followed by speed offenders and

[38] Fisher's Exact Test is reported due to low expected cell frequencies.

elderly drivers (which is similar to the focus group findings in section 7.6). The participants who endorsed the 'other' group option listed the following groups:

- easily distracted drivers (N=1)
- drivers in a new vehicle (N=1)
- drivers on a learner licence (N=1).

Table 8.23 Summary statistics for groups that would benefit from ISA[a]

	Frequency
Novice drivers	33 (82.5%)
Young drivers (eg under 25 years)	33 (82.5%)
Speed offenders	29 (72.5%)
Elderly drivers	25 (62.5%)
Professional drivers	19 (47.5%)
Other	3 (7.5%)
None	0 (0.0%)
Total	**40**

a) Participants could select multiple items, so percentages do not add to 100%.

8.3.7.7 Summary of questionnaire findings

Table 8.24 summarises the findings from the questionnaire surveys.

Table 8.24 Summary of questionnaire findings

Item	Results comment
Attitudes towards ISA	• Participants who had just experienced the variable ISA condition scored significantly lower than before they used any ISA device. • Participants had more negative attitudes to ISA after completing the route with the variable ISA condition than after completing the route with the fixed ISA. • No significant order effects were observed in these relationships.
Demographic differences	• Overall there was no evidence that demographics were related to scores on the 'Attitudes to ISA' scales.
Self-reported effects on driving	• Both ISA conditions were perceived to decrease the comfort of the driving task. • Those who had just completed the variable ISA condition rated a higher negative effect on comfort from the ISA device than those who has just completed the fixed ISA condition. • The fixed ISA condition was perceived to slightly increase participants' ability to avoid dangerous situations, whereas the variable ISA condition was perceived to have little to no effect on this ability (as explained in section 8.3.7.2).
HMI features	• Participants found the ISA easy to use and understand. • Participants felt they received enough warning of speed limit changes. • They generally found the auditory warnings more irritating than the visual warnings, but neither was rated as highly irritating. • Attitudes towards the fixed ISA condition were overall more positive than those towards the variable ISA condition.

Item	Results comment
Anticipated future use	• The majority of participants reported they would use both the fixed and variable ISA systems in the future if they were made available and/or had some design changes.

8.4 Discussion

This study examined the impact of ISA technology variations on driver speed behaviour as well as the willingness of drivers to accept ISA technology.

8.4.1 Journey time

One concern about using ISA technology often raised by drivers is that they perceive the devices will make their journey times slower. However, there was no significant increase in journey time for either the fixed or variable ISA condition within this trial, which was similar to the findings of other ISA studies (eg Hjamdahl et al 2002). The ISA conditions actually had the effect of making journey times more consistent, so that the journey time across participants was more uniform.

8.4.2 Driver speed compliance

ISA conditions generally slowed driver speeds significantly, compared with the baseline condition, across a range of road types, although the sizes of the actual changes in speed were relatively small. Overall, the proportion of distance driven at or under the speed limit increased by about 7% in the fixed and variable ISA conditions when compared with the baseline (ie no ISA). In a review of ISA studies, Young et al (2010) only reported an increase in speed compliance of about 5% for advisory ISA, indicating that the findings reported in this study are more promising for New Zealand conditions.

There were positive findings for the variable ISA condition, with greater alignment (ie nearer to compliance) with curve advisory speeds in the variable ISA condition when compared with the baseline and fixed ISA conditions. While there was no increase in the proportion of distance driven below the curve advisory speed, variable ISA was successful in increasing the distance driven at speeds between 0 and 15km/h over the curve advisory speed. On 100km/h rural single-lane carriageway roads, variable ISA increased the proportion of distance driven at speeds between 0 and 15km/h over the advisory curve speed by about 7% relative to the baseline. The significantly reduced speeds seen at curves for the variable ISA condition suggests a variable ISA could have a positive impact in addressing New Zealand's critical issue regarding speed-related crashes at curves.

The only exception to ISA effectively reducing average speed occurred in the variable ISA condition, in the 100km/h rural single-lane carriageway roads (and to some extent the 80km/h rural single-lane carriageway roads). On average, participants drove significantly faster under the variable ISA condition relative to baseline or fixed ISA conditions in the 100km/h rural single-lane carriageway zone. Closer inspection of three high-accident curves revealed that the audio-visual stimuli received from the variable ISA consistently and significantly reduced speed during the curves. It could be that drivers were speeding up between the advisory curves in the sections of road when ISA was not active to compensate for these slower speeds (appendix figure F.1, which shows average speeds along the route, is consistent with this theory), an effect that has been identified in other ISA trials (eg Comte 2000). This response could be due to some peer-pressure effect from tailgating drivers, or an attempt to 'make up for lost time'. There was no increase in travel time for either of the ISA conditions, which could relate to drivers attempting to make up time. However, there was strong evidence in the questionnaire responses that drivers were responding to social pressure from other drivers – trial participants mentioned that the variable ISA condition gave rise to non-ISA-equipped drivers tailgating them around the curves. It was further evidenced by the fact that drivers in the variable ISA condition were only driving faster than those in the fixed ISA condition on rural single-lane carriageway roads, where they may have been pressured by other drivers to speed up between the curve advisories. The speed differences between variable and fixed ISA did not occur in conditions where there was less social pressure to speed; ie during the 100km/h multilane expressway and motorway sections, where following non-ISA vehicles could easily overtake.

The social pressure regarding curve speeds could possibly be off-set by better alignment of the HMI, with more natural curve-driving profiles displayed while still reducing curve speeds overall. Setting the advisory thresholds at the appropriate speed level, and triggering them at the appropriate location to not only reduce speeds into the curve, but also to allow drivers to safely accelerate out of the curve, may enhance successful uptake. Similarly, as Young et al (2010) pointed out, any social pressure from non-ISA-equipped vehicles will also decline once there is greater market penetration of ISA, leading to smoother traffic flows and more reliable speed selection behaviour.

The main demographic influence found was for gender; females complied with speed limits more than males under all of the ISA conditions, and this could not be explained by lower speeds for females in the baseline condition. The effect of ISA on speeds was also affected by participants' general attitudes to speeding; those with more positive attitudes to speeding (ie those who felt that speeding is acceptable) drove faster than those who had more negative attitudes. However, the presence of ISA still had a positive effect on their driving behaviour relative to the baseline (ie no ISA). The implication of this is that an advisory ISA system is likely to have greater speed-reduction benefits in female drivers and drivers with negative attitudes to speeding.

The other demographic influence was that the negative-attitude group had significantly higher speeds in the variable ISA condition over the fixed ISA condition. It could be that those with negative attitudes towards speeding were also more compliant and more likely to bend to social pressure. Therefore, this would support the hypothesis that social pressure of following drivers increases speed in the variable ISA condition.

There was some evidence that the findings reported here are reasonably conservative, relative to other New Zealand speed studies. First, there was a slight bias in the sample of drivers, in that this sample of drivers had a more slightly negative attitude towards speeding when compared with national attitudes to speeding surveys. Similarly, in the baseline condition there was an experimental bias towards speed compliance in this study, with only 18.5% of drivers speeding on straight 100km/h speed conditions. This is in contrast to national figures, which suggest that 31% of drivers speed in similar conditions (MoT 2012). As these findings are reported as a relative change from the baseline, the relative differences from the baseline are consequently more likely to be smaller than could be expected in the population as a whole.

8.4.3 User perception and design preferences

An innovative aspect of this study was the examination of the HMI preferences of the participants for increasing positive user perceptions. In conjunction with the focus group findings, elements of the HMI feedback were carefully designed and tested for increasing user acceptability of the devices while also maintaining compliance levels.

Participants were generally supportive of the ISA technology. Testing the ISA conditions for themselves did not significantly improve their opinion of the fixed ISA compared to before trying it. However, participants rated the variable ISA condition less favourably than the fixed ISA, and had more negative attitudes than before they tried any ISA condition. It should be noted that these attitudes were still generally positive, but were less so after using the variable ISA. These perceptions of ISA were not affected by any demographic details, including age, gender or driving experience.

When the participants were asked to subjectively rate how ISA affected their driving, there was little difference found between the fixed and variable ISA. Both were said to have reduced the comfort of the driving task (especially the variable ISA), while the fixed ISA was said to have improved the driver's ability to avoid dangerous situations, which the variable ISA did not.

When asked about specific features of the HMI design, such as the auditory and visual warnings given, the fixed and variable ISA conditions were not generally rated differently except on some features of the visual feedback. These HMI features were rated as more annoying or harder to understand in the variable ISA condition. However, while some participants suggested they would use the fixed and variable ISA conditions as they were presented (30% fixed ISA, 10% variable ISA), the vast majority suggested that they would only use them if there were some design changes made (65% fixed ISA, 77.5% variable ISA). That the ability to customise the device had a stronger effect on variable ISA uptake shows that it is important that the settings for variable ISA be alterable. Based on the participants' comments, it appears that the ISA speed thresholds are perceived to be too low and altering these may be critical in determining uptake. Demographic differences did not affect future usage decisions.

The overwhelming feedback from participants was the need for customising the ISA technology to suit individual preferences. This was a theme also found in the focus group research. Some of the specific features that participants would like to have been able to customise (and are also features common to many satellite navigation devices) included:

- the volume of the device (both up and down)
- the threshold at which feedback is received
- the amount of warning received before a speed change or advisory
- the choice of auditory or visual feedback for different information
- the use of speech warnings rather than sound.

Other features suggested were warnings for going too far under the speed limit (ie driving too slowly); having the actual speed the vehicle is travelling displayed; and the addition of other information including school zones, railway crossings, and live updated information such as temporary speed zones.

Only a small number of participants would not consider using the devices even if they underwent design changes (two for the fixed ISA and five for the variable ISA). However, when asked why they would not use the devices, the reasons given could be overcome with the addition of customising the device, particularly for the fixed ISA option.

Finally, while not necessarily all participants recognised the usefulness of ISA for themselves, there was strong support for the use of ISA by young or novice drivers, speed offenders, and to a lesser extent, elderly drivers. In general, the groups included in this study indicated it would benefit groups other than their own (ie elderly drivers did not suggest elderly drivers, etc). This result is consistent with the recent findings of the NSW Centre for Road Safety (2010b) in which drivers saw the benefits of ISA to 'other drivers', particularly young ones, and with the findings of the focus group.

8.4.4 Fixed ISA versus variable ISA

The fixed ISA condition was found to have a positive influence on participant behaviour, while also being rated positively by drivers. If customising to the driver's preference was also possible, the vast majority claimed that they would use these devices. The results for the variable ISA condition were more mixed; in general, this condition improved driver behaviour, particularly around hazard advisory zones. However, there was stronger resistance to using this type of ISA, some of which could be addressed by greater ability to customise the device (in particular regarding feedback thresholds and audio feedback sounds) but to a lesser extent than for the fixed ISA.

Based on this research, the greater dislike of the variable ISA was best explained by participants' concerns over being a hazard when they slowed down to the advisory speeds. Participants reported (anecdotally) about feeling pressured by traffic behind them and that they did not like the stop-start nature of the way they drove within the variable ISA condition. Some support for this was found in the driving speed data, with faster speeds in the variable ISA condition when an advisory warning was not displayed.

8.4.5 Implications of the study findings

Overall, advisory ISA systems consistently improved speed compliance and therefore safety, even after a relatively short exposure to this system (one day of approximately one hour of driving with each ISA condition). The increase in speed compliance of about 7% appears to be more positive than previous overseas advisory ISA findings, suggesting that New Zealand drivers would respond well to the implementation of advisory ISA. In rural conditions with winding curves, the variable ISA condition significantly improved advisory curve speed compliance on curves. Rural curve driving is a key accident risk on New Zealand roads, and variable ISA offers a proactive and potentially cost-effective solution.

The one counter-intuitive speed finding within rural single-lane carriageway road types was that drivers with advisory ISA travelled faster (but still in compliance with the speed limit) between the advisory curves (more so for variable ISA than for fixed ISA). There was some anecdotal evidence that this increase in overall speed could be explained by social pressure, where drivers with variable ISA appeared to be responding to non-ISA-equipped drivers tailgating them. This could possibly be off-set by better alignment of the HMI with natural driving styles, such as allowing earlier acceleration out of the curve, but this requires further testing.

The key findings around the desire for a customising option of the device came from the user feedback in both this study and the focus groups (refer to chapter 7) and is a novel finding in this area. However, while full ability to customise the device might appear to increase user uptake, this would need to be balanced with any impact this may have on speed compliance. For example, one of the main reasons given for changing the auditory feedback was that it was 'irritating' or 'annoying'; however, to some extent this irritation may be necessary to increase compliance with speed warnings. Further research is therefore needed to determine the optimal balance between making devices acceptable to the user, while still offering the same benefits for compliance with speed limits and hazard advisories.

8.4.6 Recommendations

The following recommendations are made based on the findings of the experimental trial:

1 *Customised ISA trial*: Very little research has been done on the HMI, even though this is critical for successful uptake by the public. A trial with a range of customised options could examine user acceptance based on different feedback settings (eg volume, tone, visual display) or different speed thresholds.

2 *Determining effective speed thresholds*: In the variable ISA condition, the speed thresholds at which feedback is engaged, and the location before the curve at which feedback begins, will strongly influence usability. Also, the relationship between willingness to accept lower speed thresholds could be looked at from the perspective of level of incentive (eg greater vehicle insurance savings). Users are likely to be more tolerant of ISA technology if they are provided with an incremental benefit for self-selecting lower speed thresholds. As safe curve driving is a particular issue for New Zealand, determining effective ways to increase device usability will be required for successful implementation, particularly for variable ISA.

3 The experimental trials undertaken in this study were, in comparison with some other research, of small sample size and duration. A more extensive study would provide further information, particularly around the long-term effectiveness of ISA, including any compensation or over-reliance on the system, and the level of use of the device; this would aid in the decision making around whether to deploy an advisory ISA system in New Zealand.

9 ISA benefit–cost analysis

9.1 Introduction

9.1.1 System outline

This analysis used the data collected during these field trials of an advisory ISA system (chapter 8) together with international literature, where applicable, to determine the crash-reduction benefits and economic benefit–cost analysis for an advisory ISA in New Zealand.

The ISA system envisaged here is an autonomous (in-vehicle) ISA, in which each vehicle uses GPS and dead-reckoning (where the ISA device has this capability) to locate itself on a digital map held on the in-vehicle ISA device and read the appropriate speed limit from that map.[39]

9.1.2 Approach

The approach adopted to assess the benefits involved first looking at the likely reductions of the advisory ISA trialled in this study (sections 9.2–9.4), then estimating the costs associated with the deployment and maintenance of an advisory ISA (section 9.5). Section 9.6 contains the benefit–cost analysis; section 9.7 discusses the findings; and section 9.8 makes recommendations based on this work.

The assessment of benefits was undertaken in two stages. First, the impact of the two ISA variants on the speed profiles of the subjects who undertook the field trials was investigated. Then crash reductions were predicted, using a number of alternative speed–crash relationships.

9.2 Benefits of advisory ISA

The major impact of ISA is on crash risk. Some researchers have reported that further benefits may result from reduced fuel consumption and emissions (Lai et al 2012a). While they were potentially significant, these fuel and emissions-related benefits have not been included in this analysis.

While some might argue there may be a disbenefit due to increased journey time, journey time savings derived from illegal activities such as exceeding the speed limit were not included in this analysis. Additionally, the findings of the experimental trial reported in chapter 8 showed that over the trial route, which had travel times of about an hour, there was a difference of less than one minute between the different ISA conditions (which was not a statistically significant difference).

This analysis of benefits focuses solely on the crash reduction that could be achieved by ISA, using the data from the experimental trials. The route sections used and information regarding the manipulation of the raw data from the experimental trials is provided in appendix section F.1.

9.2.1 Impact of ISA on speed profiles

The advisory ISA investigated in this study provided the driver with visual stimuli when they exceeded either the fixed speed limit, or in the case of the variable ISA, both when the speed limit or signed curve advisory speed were exceeded. Audio stimuli were provided to the driver when they exceeded the speed limit by more than 3km/h, and when they exceeded the advisory speed by more than 15km/h.

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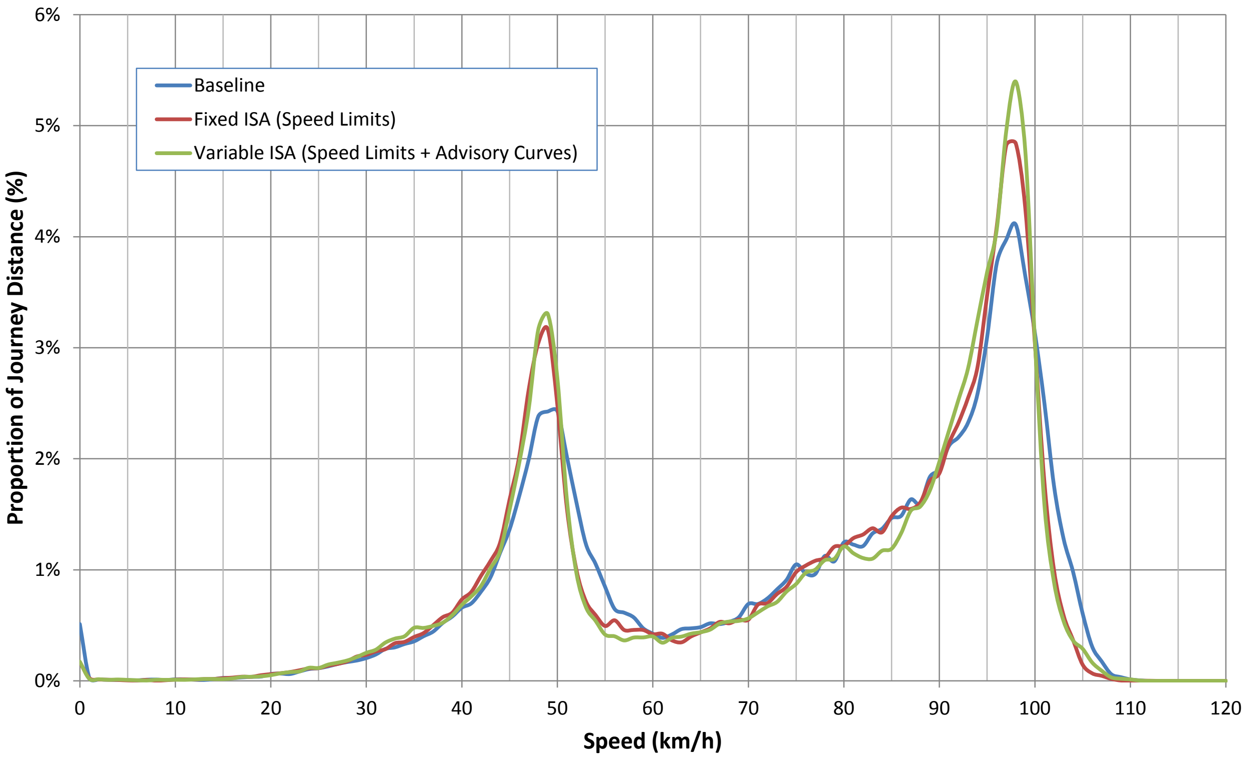
[39] Assuming a fully functioning speed limit management system and 'map'.

Other forms of ISA are more intervening and may limit the vehicle's maximum speed when activated (voluntary ISA), or continually (mandatory ISA). Each of the ISA typologies seeks to modify the speed profile of drivers.

The speed profile data collected in these trails is shown in figure 9.1, with plots of speed as it varies over the route presented in appendix section F.2.

Figure 9.1 Speed profile over the route used in the experimental trials[40]



Looking at figure 9.1, it can be seen that in the peaks around 50km/h and 100km/h for both the fixed ISA and the variable ISA, there was an increase in the proportion of journey distance travelled at or close to the speed limit. Separating out the 50km/h and 100km/h speed limit areas (figures 9.2 and 9.3), we see both an increase in the proportion of journey distance spent travelling at or just below[41] the speed limit, as well as a reduction in the proportion of journey time exceeding the speed limit. It is also worth noting that the variable ISA condition had a slightly greater increase in the proportion of journey distance spent travelling at or just below the speed limit than the fixed ISA or baseline condition. For those using the variable ISA, figure 9.2 shows an increase in the proportion of journey distance spent travelling between 30km/h and 35km/h, which is likely to relate to the 35km/h advisory speed set for the speed humps in the school zone on Bell Road.

[40] Plotted as a continuous function for ease of viewing the differences in each profile.

[41] This relates to the error bias in speedometer readings, which results in an over-read of 3% on average, and the escalating ISA stimulus with audio warnings not being activated until the vehicle was travelling 3km/h above the speed limit.

Figure 9.2 Speed profiles in 50km/h speed limit zones on the route used in the experimental trials

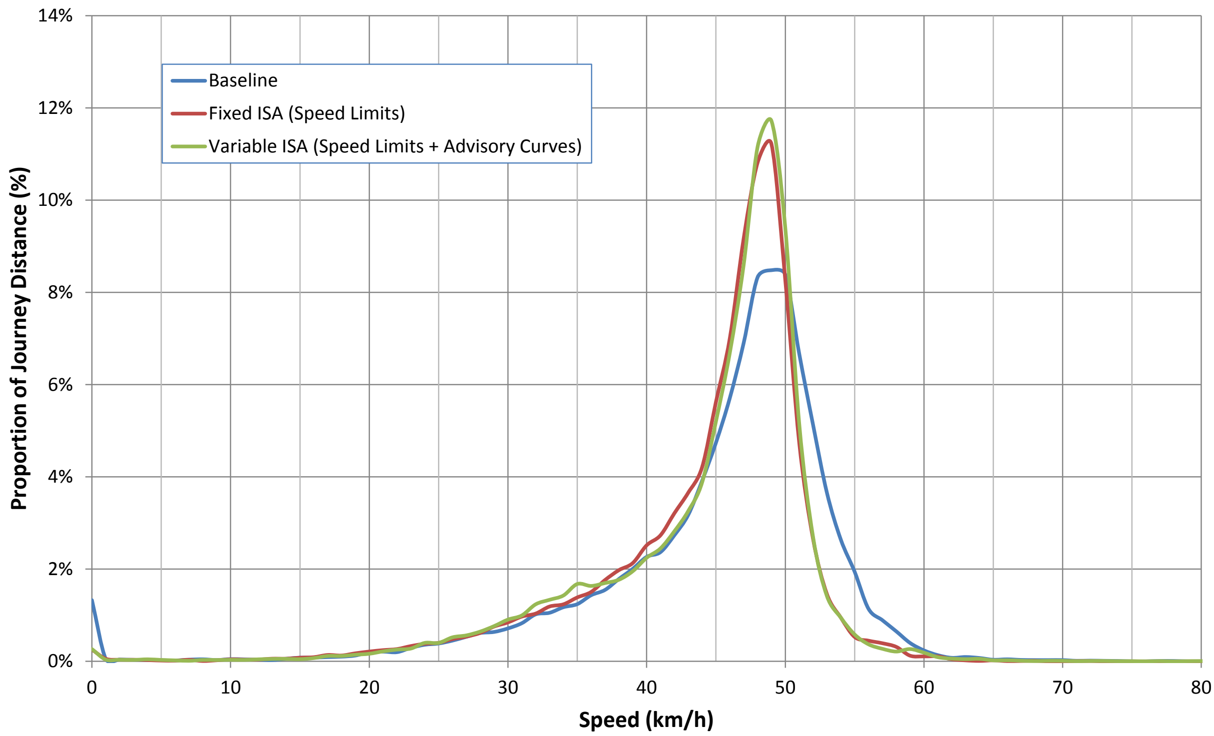
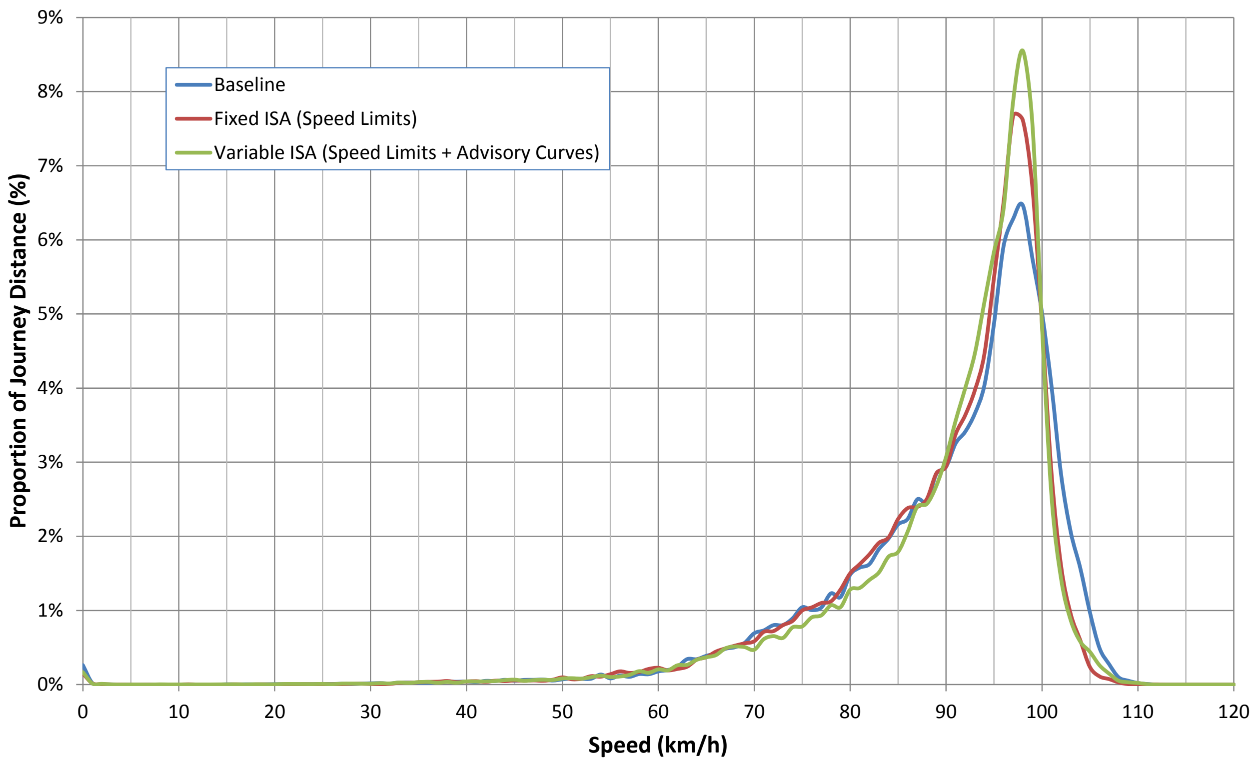


Figure 9.3 Speed profiles in 100km/h speed limit zones on the route used in the experimental trials



9.2.2 Speed–crash relationships

Clearly the advisory ISA systems tested in this study had an impact on travel speed profiles. The next step was to assess the likely crash-reduction benefits of these changes.

There are several speed-crash risk models available, which can be broadly categorised according to the extent to which they take account of changes in the shape of the speed distribution. These include:

- mean-speed crash risk models (models originally proposed by Nilsson1981 and 2004)
- mean-speed and shape-of-speed-distribution models (models proposed by Kloeden et al 2001 and 2002)
- individual crash risk models (models proposed by Taylor et al 2000 and 2002).

While the models considered here have all been developed using data from outside New Zealand, it was assumed that they could be applied here to provide a good indication of the likely crash-reduction benefits of implementing an advisory ISA system in New Zealand. This assumption was based on the review of the transferability of the Nilsson model in particular, which was undertaken by Cameron and Elvik (2010).

9.2.2.1 Mean-speed crash risk models

Mean-speed crash risk models proposed by Nilsson in 1981 can be used to determine the change in crash risk associated with a change in mean speed.

Nilsson's Power Model expresses the change in crash risk in relation to the change in mean speed (V) raised to a power (b3).

$$\frac{Crashes\ After}{Crashes\ Before} = \left(\frac{V_{After}}{V_{Before}}\right)^{b3} \qquad \text{(Equation 9.1)}$$

The original models relied almost exclusively on data collected on rural roads. However, in 2004, Elvik revisited the earlier models, added new studies and developed models for both high-speed situations (rural roads and motorways) and low-speed situations (urban roads and residential streets), as well as undertaking a subsequent related meta-analysis in 2009.

Table 9.1 Power factors (b3), sourced from Elvik (2009) cited in Cameron and Elvik (2010, table 8)

Crash severity	Rural roads/freeways	Urban/residential roads
Fatal	4.1	2.6
Serious injury	2.6	1.5
Minor injury[a]	1.1	1.0

a) Slight-injury accident in Cameron and Elvik (2010), quoting Elvik's (2009) power estimates.

One strength of these mean-speed models is that they have been constructed to allow the estimation of crashes by severity category (fatal, serious and minor injuries). However, the models have been typically based on data resulting from either speed limit changes, or in some cases smaller changes related to increased enforcement activity. This implicitly assumes that the speed distribution will simply be shifted and that the shape will remain unchanged. While this means that Nilsson's Power Model is not suitable for the more intervening types of ISA (voluntary and mandatory), where the speed distribution is typically truncated, the change in shape of the speed distributions for advisory ISA are not as pronounced as the changes reported in other studies (Carsten and Tate 2005). Therefore, for the purposes of this study it was assumed that Nilsson's Power Model would give an indication of potential savings, even though figures 9.2 and 9.3 show that the shape of the speed distribution had changed somewhat.

9.2.2.2 Mean speed and shape of speed distribution

This set of models seeks to take into account, to varying degrees, the change in the shape of the speed distribution in a range of ways: by considering the standard deviation of speeds, sometimes using the coefficient of variation; by considering the proportion of traffic exceeding the speed limit by a fixed amount; or by using the mean speed of those exceeding the speed limit.

Such models include those developed by Taylor, Lynam and Baruya (2000) for urban roads and Taylor, Baruya and Kennedy (2002) for rural roads, which are considered here.

- *Urban models*: Taylor, Lynam and Baruya, at TRL Limited, developed two speed-crash risk models for urban roads that explain about 90% of the variation in accident data when taken together with influential traffic and road factors (2000).

  The first model, U1, uses both the mean free speed, V, and the coefficient of variation of speed, C_v (ie standard deviation divided by mean speed), to explain variations in injury crash frequency. This model was applied to each 10m section on the trial route and the average was then taken to determine the predicted crash reduction over the route.

$$A = V^{2.252} e^{5.893*Cv}$$

(Equation 9.2)

  The second model, U2, uses both the proportion of drivers exceeding the speed limit, P, and the mean speed by which drivers exceed the speed limit, V_{ex}, to explain variations in injury crash frequency.

$$A = P^{0.141} e^{0.175*Vex}$$

(Equation 9.3)

- *Rural models*: Taylor, Baruya and Kennedy (2002, cited in Cameron and Elvik 2010) revised and simplified their rural models following a review of their earlier models developed under the MASTER project (1998, cited in Oei and Polak 2002), under which a speed–crash relationship (the EURO model) was developed for European rural single-lane carriageway roads. They developed two models; the first relates the frequency of injury crashes to mean free speed; and the second relates the frequency of injury crashes to the proportion of drivers exceeding the speed limit. Although Taylor et al (ibid) concluded that the first model (equation 9.4) explains more variation in crashes than the second (equation 9.5), this first model, when used for comparative analysis where all road characteristics are unchanged (as per the form shown in equation 9.4), is essentially a power model (like Nilsson's). As we have already assessed the crash-reduction potential using the Nilsson power model, equation 9.5 was used for this study, as it takes some account of the change in the shape of the speed distribution.

$$A = V^{2.479}$$

(Equation 9.4)

$$A = P^{0.1137}$$

(Equation 9.5)

9.2.2.3 Individual crash risk models

These models consider the risk associated with drivers' speed choices. Recent models (Kloeden, Ponte and McLean 2001; and Kloeden, McLean and Glonek 2002) considered the relative risk associated with speed choices above and below the mean speed, finding that speed was the primary risk factor.

Kloeden, Ponte, and McLean's 2001 models (equation 9.6) were based on crash reconstruction from data collected in South Australia for free-travelling vehicles involved in crashes on rural roads with speed limits of 80km/h or more. Kloeden, McLean and Glonek's 2002 models (equation 9.7) were based on a reanalysis of data from a 1997 study by Kloeden, McLean, Moore and Ponte that examined speeds in urban areas (60km/h speed limit zones). For the purposes of this study it was assumed that this model would provide a good estimate of the expected crash-reduction benefits on 50km/h roads.

Although the Kloeden models purported to represent all casualty or injury crashes, the crashes included in the studies were in fact those to which an ambulance was called. In New Zealand, this is roughly equivalent to a crash that results in death or serious injury, rather than all injury crashes.

$$A = e^{0.07039V_{diff}+0.0008617V_{diff}^2}$$

(Equation 9.6)

where V_{diff} is the speed difference from the mean, and valid for speed differences from -10km/h to 30km/h.

$$A = e^{0.1133374V_{diff}+0.0028171V_{diff}^2}$$

(Equation 9.7)

where V_{diff} is the speed difference from the mean, and valid for speed differences from 0km/h to 20km/h.

For the purposes of this study, the relative risk was held constant where the speed difference fell outside the range for which the applicable model was valid (eg figure 9.4). The relative-risk curve was then combined with the speed profile to give the proportion of journey spent travelling at a particular speed and the relative risk of travelling at that speed in relation to the mean speed – the risk profile (figure 9.5). The area under this curve represented the relative crash risk, and the difference in the areas was used to determine the expected crash reduction.

Figure 9.4 Relative risk curve derived using Kloeden, Ponte and McLean's (2001) model (equation 9.6), with values held constant outside of the model's applicable range, for application in this study

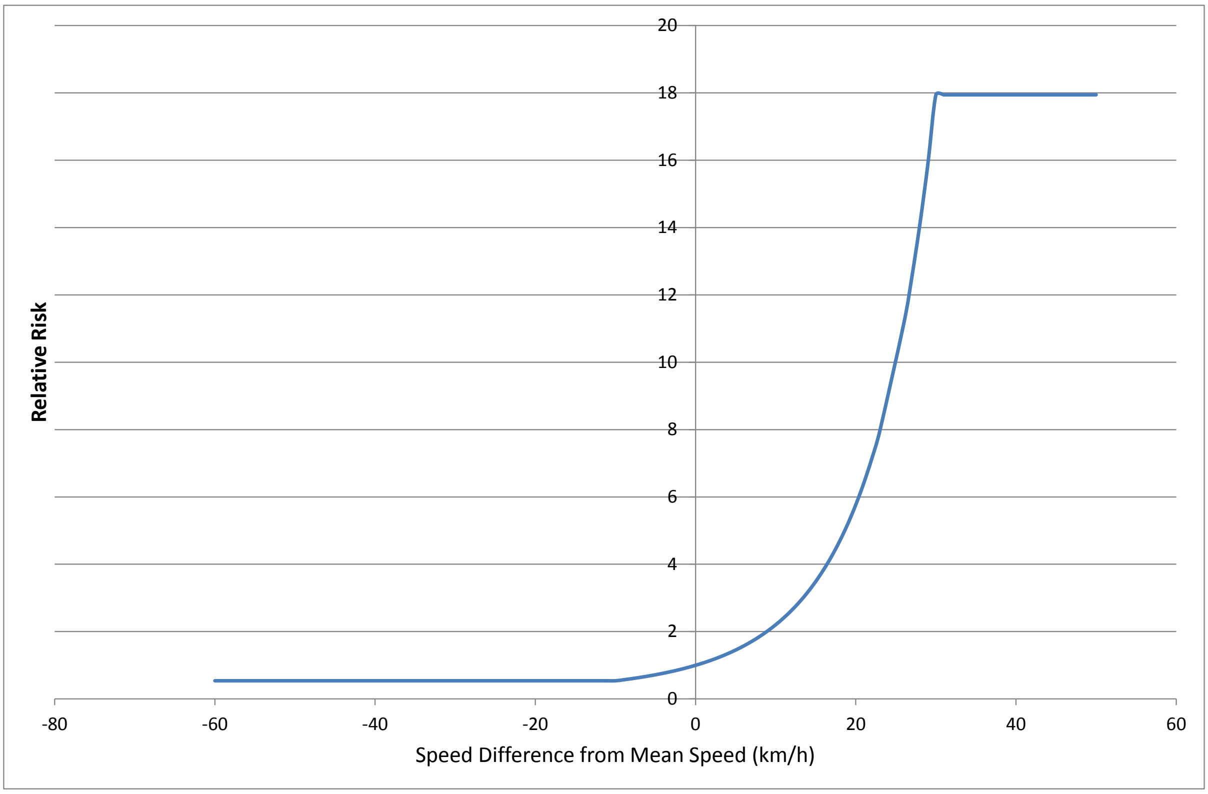
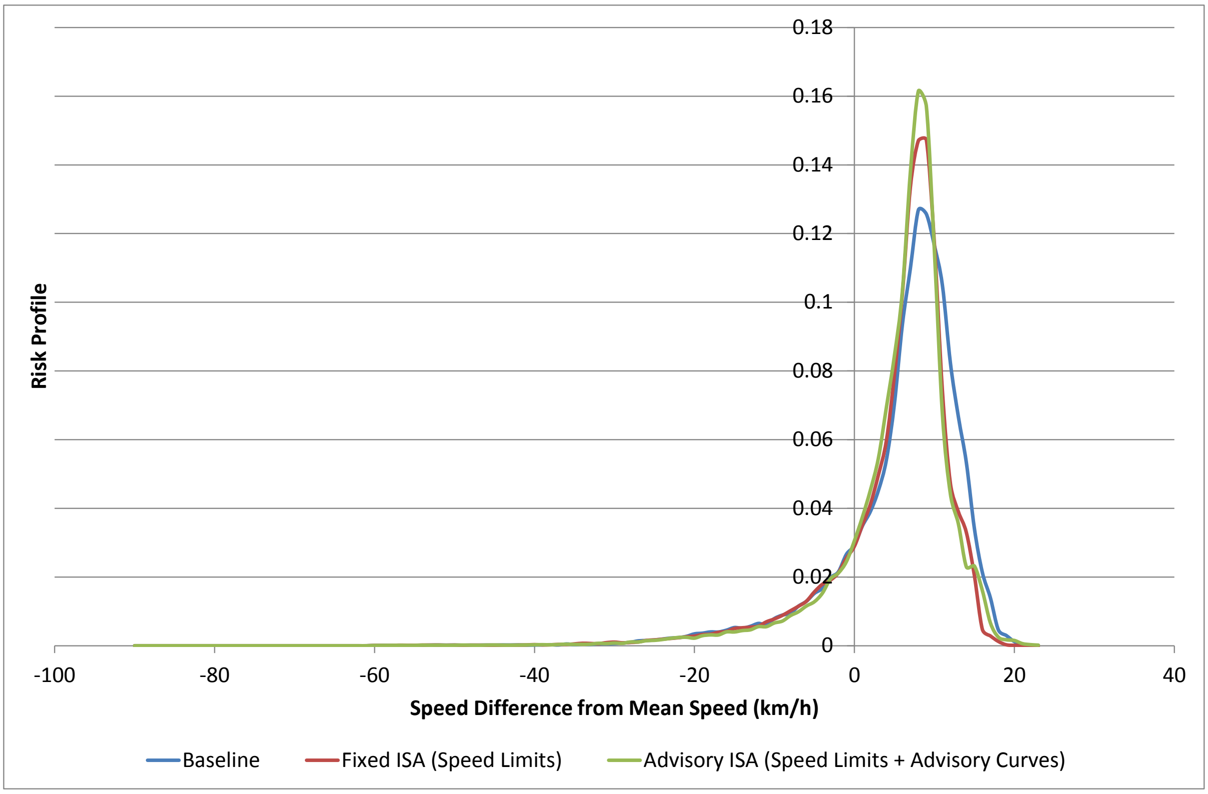


Figure 9.5 Risk profile for 100km/h trial route sections for the three ISA conditions, using Kloeden, Ponte and McLean's (2001) model



9.2.2.4 Summary of predicted injury crash reductions

- *Fixed ISA*: The results of the application of the speed-crash risk models show that the greatest reductions for fixed ISA were expected to be achieved in 50km/h and 80km/h areas, with considerable variation between the three types of models used (see table 9.2). These results were consistent with other ISA studies, which have found ISA to be more effective at reducing speeds in the lower speed zones found in urban areas (Young and Lennie 2010, citing Agerholm et al 2008; Jamson 2006; Päätalo et al 2002).

Table 9.2 Predicted crash savings for fixed ISA relative to baseline

Road type	Mean-speed crash risk models (Nilsson/Elvik power model)			Mean-speed & shape-of-speed-distribution models (Taylor et al models)	Individual crash risk models (Kloeden et al models)
	Fatal crashes (%)	Serious-injury crashes (%)	Minor-injury crashes (%)	All injury crashes (%)	Fatal and serious-injury crashes (%)
50km/h	5%	3%	2%	8% & 15%	22%
80km/h (single-lane carriageway)	6%	4%	2%	5%	9%
100km/h	1%	1%	0%	n/a	5%
• 100km/h single-lane carriageway	-2%	-1%	0%	0%	-3%
• 100km/h multilane carriageway	3%	2%	1%	n/a	6%
- 100km/h expressway	3%	2%	1%	n/a	5%
- 100km/h motorway	3%	2%	1%	n/a	6%

The results also show that the relatively small crash reductions predicted for 100km/h roads were largely as a result of the zero or negative crash reductions predicted for the 100km/h single-lane carriageway roads.

One explanation of the poor performance of fixed ISA on single-lane carriageway roads is the low speeds that were travelled in the on-road trials (82.4km/h and 57.9km/h baseline mean speeds for 100km/h and 80km/h single-lane carriageway sections respectively), which meant that the participants travelling on these sections did not often experience the visual or audio stimuli from the ISA unit. Over the 100km/h single-lane carriageway sections and the 80km/h sections, less than 3% of the distance over the trial route and over all the participants included in the dataset, was spent speeding (see appendix section F.3 for further statistics). Therefore one could argue that any ISA effect may have been swamped by the natural variation in drivers' speeds.

- *Variable speed advisory ISA*: While the additional benefits of the variable ISA were expected to only apply to curves, the crash benefits associated with a mean-speed reduction were included in this analysis, as the results presented in section 9.7 suggested that while variable ISA resulted in reduced curve speeds, there may have been a social pressure effect from tailgating drivers, or compensatory behaviour occurring with drivers speeding up on straight sections of road to make up for time 'lost' on the curves, as discussed in section 8.4. Young et al (2009) put forward a similar explanation for the greater effect that they found ISA had on reducing speeds at the upper end of the distribution than on reducing average speeds, proposing that drivers increase their lower speeds to compensate for the reductions in top speed or because they are using ISA as a form of cruise control. This appears to be supported by the lower crash risk reductions, and in some cases crash risk increases, achieved under the variable ISA as compared with the fixed ISA. Of particular note was the crash increase predicted for the 100km/h single-lane carriageway speed limit zones and the subsequent increase predicted for 100km/h speed limit zones overall. However, it should also be noted that the apparent compensatory behaviour was likely to have been influenced by the HMI used in the experimental trials. Frustration may have arisen because of the continuation of the advisory speed zone to the end of the curve, rather than to the apex of the curve, and also because some participants felt the advisory speed thresholds were set too low (refer to chapter 8).

Overall, the results for the variable ISA (table 9.3) were generally poorer than those for the fixed ISA. Lower crash reductions were predicted for variable ISA in all cases except for the 80km/h roads. This could be explained by the theory (above) that the results are unreliable for sections where mean speeds were considerably below the speed limit (the single carriageway sections restricted by alignment in this trial).

Table 9.3 Predicted crash savings for variable speed advisory ISA relative to the baseline

Road type	Mean-speed crash risk models (Nilsson/Elvik power model)			Mean speed & shape of speed distribution models (Taylor et al models)	Individual crash risk models (Kloeden et al models)
	Fatal crashes (%)	Serious-injury crashes (%)	Minor-injury crashes (%)	All injury crashes (%)	Fatal and serious-injury crashes (%)
50km/h	5%	3%	2%	8% & 13%	14%
80km/h (single-lane carriageway)	5%	3%	1%	-10%	-4%
100km/h	-2%	-1%	0%	n/a	2%
• 100km/h single-lane carriageway	-8%	-5%	-2%	-3%	-14%
• 100km/h multilane carriageway	1%	1%	0%	n/a	5%
- 100km/h expressway	1%	0%	0%	n/a	3%
- 100km/h motorway	2%	1%	1%	n/a	5%

- *Predicted injury crash reductions*: Having used a number of models to determine a range of speed-related crash-reduction factors, a single model was chosen in order to calculate the crash-reduction benefits associated with the implementation of an advisory ISA system in New Zealand. While the mean-speed model (Nilsson power model with power factors revised by Elvik) was valid, the speed profiles (section 9.2.1) clearly showed an effect on the shape of the speed distribution, and therefore the power model was likely to be under-predicting the expected crash reduction.

  Aarts and van Schagen (2006, cited in Cameron and Elvik 2010), concluded that the relationships established by Kloeden, Ponte and McLean (2001) and Kloeden, McLean and Glonek (2002) for rural and urban roads, respectively, best describe the links between individual vehicle speed and casualty-crash risk, and as the Taylor et al models are only applicable to some situations, the Kloeden et al models were selected for this study.

  However, in order to capture the benefits to minor-injury crashes, the crash-reduction proportions for fatal, serious-injury, and minor-injury crashes determined by the Nilsson power model were used to estimate minor-injury crash reductions. This gave minor-injury crash reductions as 30% of the fatal and serious-injury crash reduction for both fixed and variable ISA over the three speed limit zones.

  Due to the questions around the validity of the single carriageway results, the 80km/h and 100km/h sections were combined and reanalysed to produce an estimate of crash risk for rural roads. This assumed that the rural roads in the trial were representative for New Zealand. Ideally, the actual proportions of different carriageway types would be used. Similarly, it was assumed that the results obtained from the urban 50km/h sections in the trial would be applicable to all urban situations. The final results used for the calculation of crash benefits are shown in table 9.4.

Table 9.4 Summary of final predicted crash savings for the implementation of an advisory ISA system in New Zealand

Road type	Fixed speed limit ISA			Variable speed advisory ISA		
	Fatal (%)	Serious injury (%)	Minor injury (%)	Fatal (%)	Serious injury (%)	Minor injury (%)
Urban	22%	22%	7%	14%	14%	4%
Rural	5%	5%	2%	2%	2%	1%

9.3 Variable speed advisory ISA on curves

Almost without exception, the European and the more recent Australian ISA studies have focused primarily on road safety issues related to urban areas. The predominant crash problem in New Zealand relates to mainly to rural, not urban roads, and in particular, loss of control on rural roads.

A recent investigation of rural state highway curves (ie with speed limits greater than 70km/h) found that of the 17,360 curves where the radius dropped below 400m, 16,740 had expected 85th percentile negotiation speeds of less than 95km/h. Of the 3428 injury crashes recorded between 2007 and 2011that occurred on the 17,360 state highway curves identified as having a radius that drops below 400m, 3316 injury crashes (97%) had occurred on curves where the safe negotiation speed was expected to be less than 95km/h.

Whereas the vast majority of ISA studies reported to date have focused on compliance with fixed speed limits (fixed ISA), this New Zealand study has included an investigation into the impacts of an ISA system that provides advice on the negotiation speed for curves as well as speed limit advice (ie variable ISA). The benefits derived from variable ISA are effectively those derived from fixed ISA on the links between curves, plus the additional benefits derived from the speed advice given on curves.

9.3.1 Curve advisory speeds

The variable ISA provided additional speed advice when drivers were negotiating curves where curve speed advisory signs had been installed. These curve speed advisory signs are permanent warning signs – some provide a schematic indication of the forward road alignment[42] and are installed together with a supplementary speed advice plate[43] that provides advice on the comfortable negotiation speed for light vehicles in dry weather (figure 9.6).

The need for, and the value of, the curve advisory speed is determined using speed and g-force measurements undertaken using a ball-bank gauge.[44]

The signs are located in advance of the curve according to the curve approach speed, and in all cases the speed advice is rounded to the nearest speed value ending in 5km (ie 45, 55, 65, etc), to distinguish the advisory speed from the legal speed limit, which is always a multiple of 10km.

[42] PW16 to PW24 –see www.nzta.govt.nz/resources/motsam/part-1/docs/motsam-1-section-06.pdf (soon to be replaced by the *NZ Transport Agency Traffic control devices manual* (TCD Manual)).

[43] PW25.

[44] As outlined in appendix C of the *Manual of traffic signs and markings* (NZTA 2011). www.nzta.govt.nz/resources/motsam/part-1/docs/motsam-1-appendix-a3.pdf

Figure 9.6 Example of a curve speed advisory sign (sourced from the NZTA *Manual of traffic signs and markings* 2011)

9.3.2 Human-Machine Interface (HMI) of variable speed advisory ISA

Study trial participants were given a visual stimulus in the form of a red curve-advisory symbol on their ISA unit when they exceeded the curve advisory speed while travelling on the curve. If they exceeded the curve advisory speed by more than 15km/h, audio feedback was triggered in the form of a single repeated beep. The strongest feedback (a repeated triple beep) was triggered if a participant exceeded the curve advisory speed by more than 30km/h. These stimuli were active until the participant either reduced their speed below the threshold or exited the end of the curve advisory zone.

The curve advisory stimuli also included an advance warning 'AMFM' beep to alert drivers to the upcoming curve. This warning was triggered 75m in advance of the start of the curve.

These stimuli and the HMI applied in the trial have been covered in more detail in chapter 8.

9.3.3 Impact of variable speed advisory ISA curve advice

9.3.3.1 Curve advisory speeds

The ISA field trial route was selected to provide data on the impact of the two ISA systems in a range of driving environments, including residential streets, urban arterials, motorways, expressways and rural roads. For the purposes of this analysis, only the impact of curve advisory advice on rural roads was considered. While there is one rural curve on the motorway off-ramp (Centennial Highway) section of the trial route, the necessary data was not available for this curve, and therefore the analysis covered SH58 only.

The rural road section, SH58, is a 15km section of rural road. The first section, approximately 9km long, covers rolling to steep terrain with a 100km/h speed limit. The second section, approximately 3km long, is flat and winds around the harbour and has an 80km/h speed limit; the remainder is an urban section with a 50km/h speed limit.

As a whole, the rural section of SH58 contains 48 curves with radii less than 400m. While 29 of these curves potentially warrant speed advisory signs, on the basis that the curve speed is expected to be 20km/h or more below the approach speed, the sequencing of curves is such that only nine sets of advisory speed signs (four within the 100km/h section) have been installed. While there are nine sets of signs, in five cases the advisory speed signs cover two successive curves. Details of the curves and advisory speeds are shown in appendix section F.5.

For this analysis, the 85th percentile curve approach speed and curve speed (shown in appendix section F.5) were assessed based on the highway geometry, using the same method as adopted by Tate and Turner (2007), Cenek and Davies (2004) and Cenek, Henderson and Davies (2012).The 85th percentile curve speed was based on the tightest 30m of the curve, while the 85th percentile approach speed was based on the highway geometry over the preceding 500m. As such, these measures did not take into account the speed limit, the full impact of an upstream curve that may limit the approach speed, or the impact of gradient.

While there is a reasonable relationship between the 85th percentile speeds estimated from highway geometry and those adopted by drivers (Turner and Tate 2007), they are not equal, and the relationship between the estimated curve speed and the proposed advisory speed as shown on the signs is less reliable due to the requirement to round these to the nearest value ending in 5km. In general, the advisory speed shown on site and used within ISA are similar or less than those estimated using highway geometry; the notable exception being curve D in figure 9.7, where the estimated curve speed is 75km/h but the advisory sign and ISA speed advice is 85km/h.

9.3.4 Impact of variable speed advisory ISA

The travel profiles, expressed in terms of the 85th percentile speed, recorded every 10m, are plotted in figure 9.7, together with the nine curve advisory locations on rural SH58 over which the variable ISA provided curve negotiation speed advice. The 85th percentile speed was used, as this is related to the crash prediction modelling used later in this chapter.

Figure 9.7 Speed profiles over SH58 showing curve advisory speeds (distance in metres)

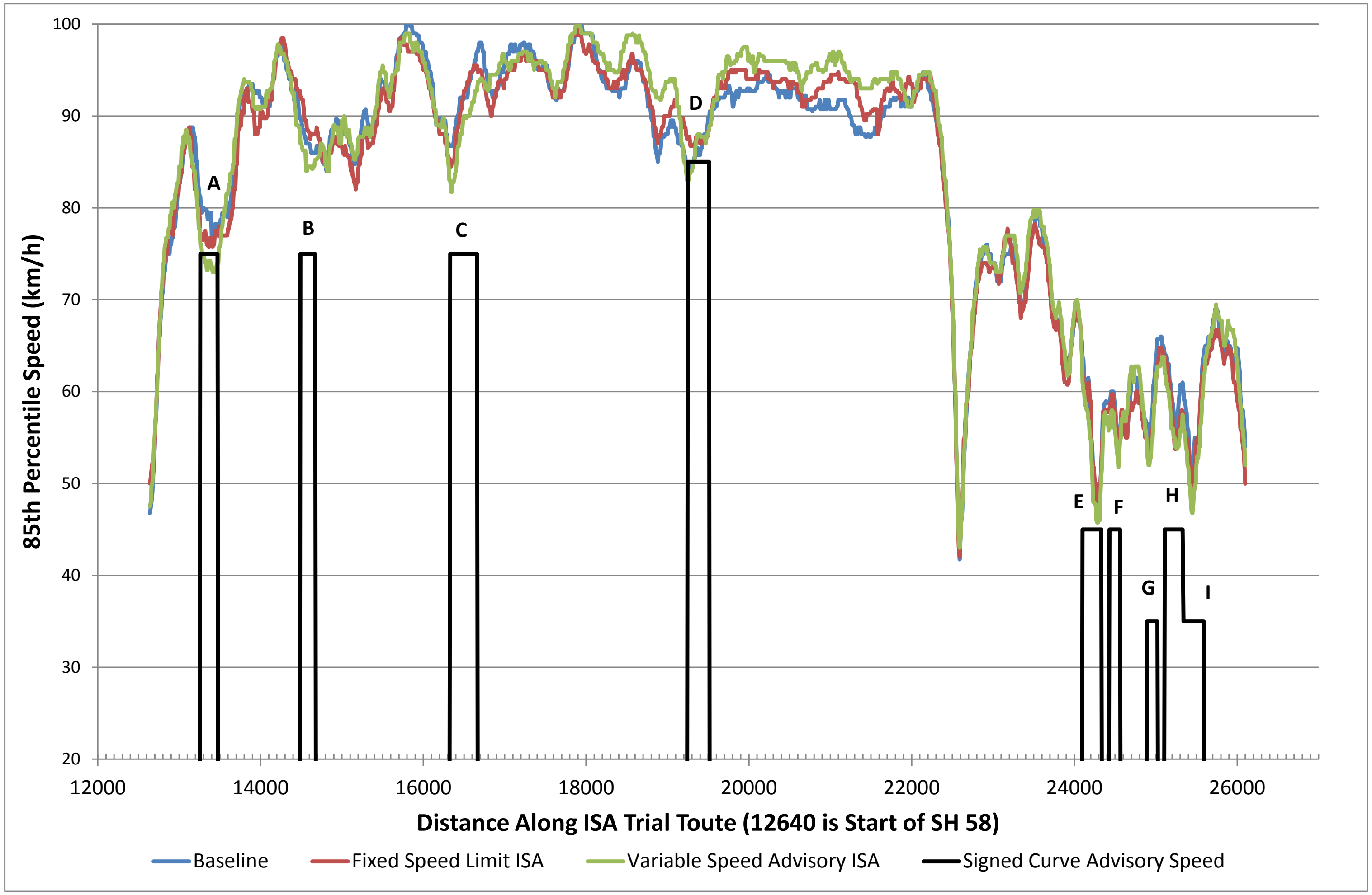
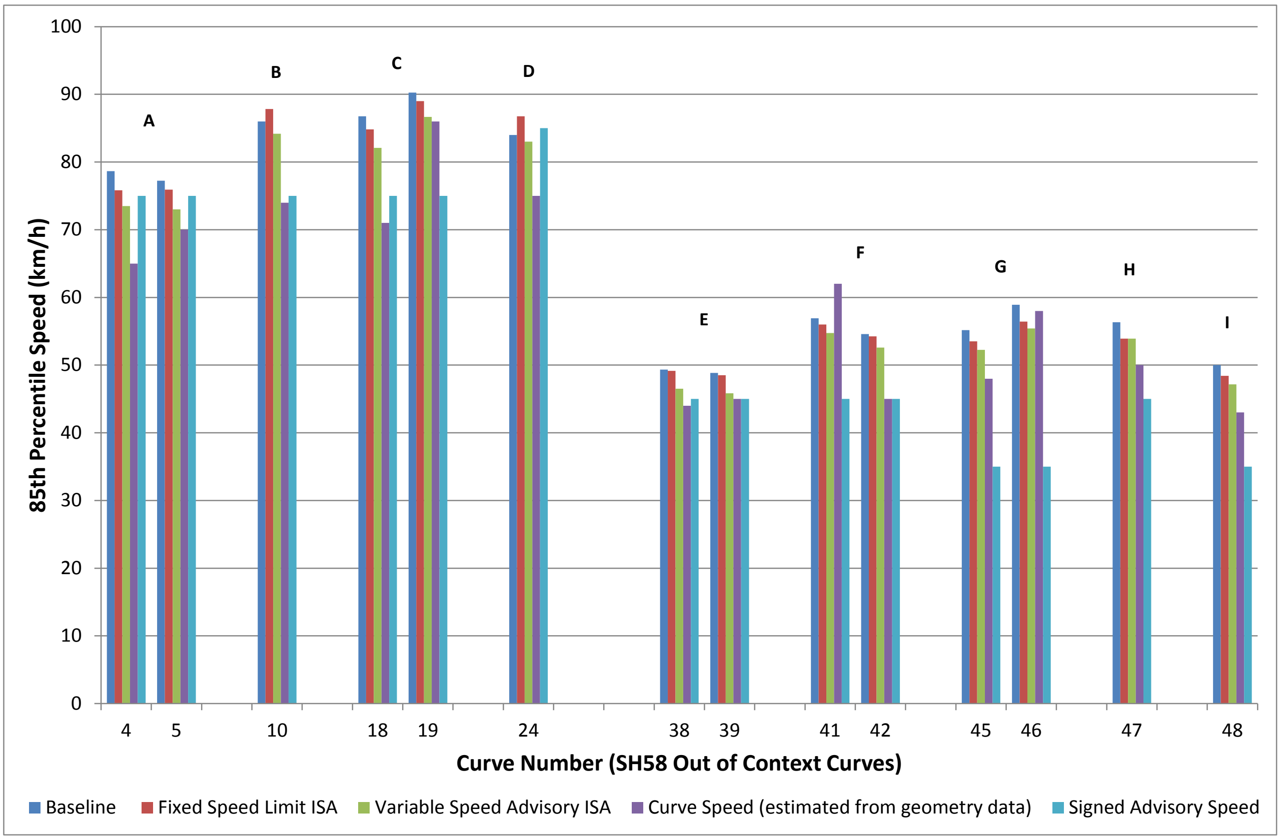


Figure 9.7 shows that in all cases, the ISA curve negotiation speed advice resulted in lower curve negotiation speeds at all curves where it was provided. However, in only three cases (curves A, D and E) the 85th percentile speeds adopted by the study participants approached that of the speed advisory.

It is also worth noting that for a large proportion of the trial route (excluding the signed advisory curves, particularly between approximately 18,000m and 22,500m to the roundabout), the variable ISA profile speeds were higher than those in the baseline, reflecting the possible response to drivers feeling ‘pressured’ as discussed in chapter 8.

Figure 9.8 looks at a range of speed metrics for each curve and shows a number of anomalies with respect to the estimated curve negotiation speed and the advisory speeds posted for the curves. These anomalies in the signposted advisory speed compared with the speed driven by participants under each ISA condition explain some of the negative feedback from participants, and are likely to have contributed to any compensatory behaviour where drivers sped up outside of the signed curves either because they felt pressured by other drivers or to make up for ‘lost’ time.

Figure 9.8 85th percentile speed metrics on advisory curves



9.3.5 Injury crash reduction of variable speed advisory ISA

9.3.5.1 Approach

The original intention (as outlined in the project brief) was to use the curve crash prediction model developed by Cenek and Davies (2004) and Cenek et al (2012) to establish the expected crash reductions on curves where ISA also provided speed advice. This model expresses the likelihood of an injury crash occurring on a curve as a function of:

- the region within New Zealand, reflecting aggregate properties and weather

- road-surface characteristics such as SCRIM, rutting and roughness
- a number of geometric elements, including approach gradient and curve length
- curve context.

The curve context variables include the approach speed and the curve speed. In both cases the speed in question is that estimated using the highway geometry and is an approximation for the 85th percentile speed (this estimated curve speed is shown in figure 9.8). The two context variables – the difference between the approach speed (measured over the 500m prior to the curve) and the curve speed – are highly significant variables in the model. The difference between the approach speed and the curve speed has also been found by other New Zealand researchers to have a major impact on curve crash rate (Jackett 1992; Koorey and Tate 1997; Tate and Turner 2007).

The context variable in the Cenek and Davies model, and the other research, essentially predicts the likelihood of an approaching driver making a judgement error when assessing the correct negotiation speed for the curve. The analysis of the impacts of curve speed advice provided by variable ISA, undertaken in chapter 8, showed that in general, variable ISA had little or no impact on the pre-curve speed (hypothesised to be due to the HMI used) but did impact significantly on the curve negotiation speed, as shown in figure 9.7.

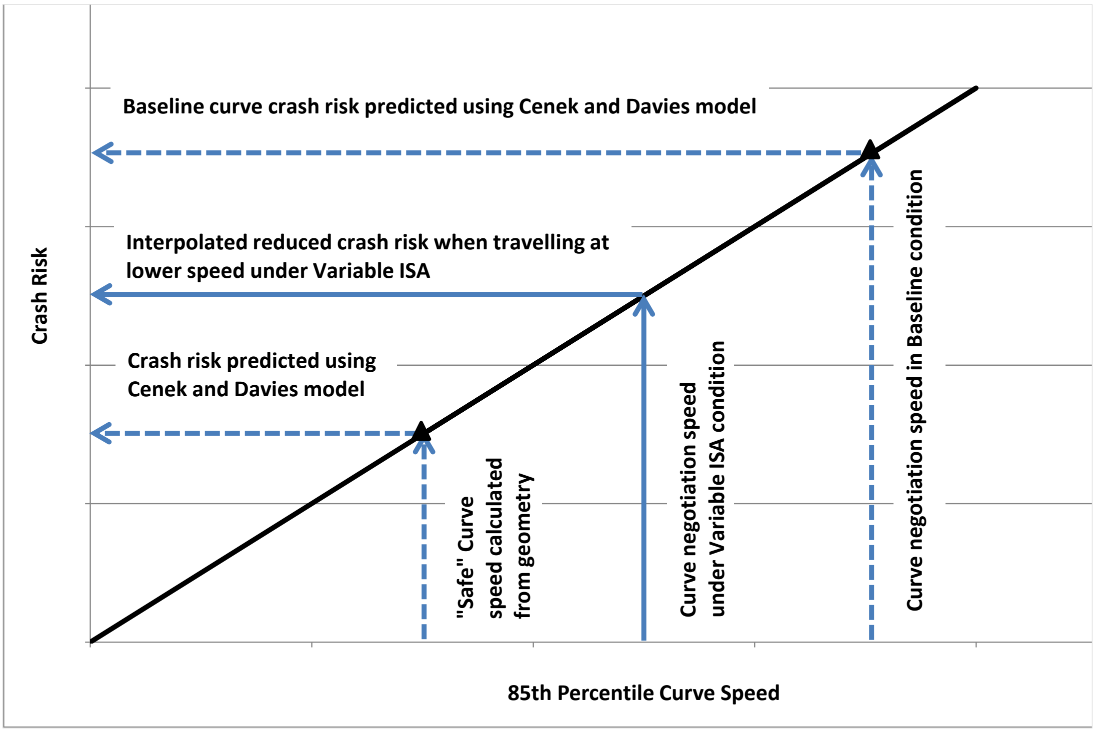
The drop in subjects' curve negotiation speeds relative to the approach speed would result in an increase in predicted crash rate if the Cenek and Davies model (or other similar models) were used, as the models assume that the greater the difference between approach and curve speed, the more the curve is out of context and the higher the predicted crash rate will be. In reality, the curve had not changed or become more out of context, but the negotiation speed was lower, and therefore safety was improved. The Cenek and Davies model, as it is normally applied, is therefore not suitable for estimating the additional curve crash-reduction impacts of curve speed advice from ISA, and an alternative approach was required; one that recognised the difference between the baseline curve negotiation speed and the curve design speed.

If the curve crash rate is reconfigured to be a function of the curve speed as estimated by the curve geometry and the negotiation speed, a reduction in the negotiation speed as a result of speed advice from ISA would reduce this difference and imply a crash reduction.

Taking the baseline (no ISA) curve negotiation speed as representing the speed currently adopted by the driving population, the curve crash rate was predicted using the Cenek and Davies model. Similarly, if the curve was negotiated at the curve speed as defined by the geometry (the 'safe' curve negotiation speed), there was no increased risk relating to the curve (it is as if the curve did not exist), and the crash rate would be that for travelling a section of highway at that (curve negotiation) speed. It was therefore possible to estimate the reduction in crash likelihood as the proportional reduction[45] in curve negotiation speed under variable ISA, relative to the baseline negotiation speed and the calculated 'safe' curve negotiation speed. This approach is shown schematically in figure 9.9.

[45] In the absence of evidence, a straight-line relationship was assumed.

Figure 9.9 Schematic of crash-reduction approach for variable speed advisory ISA



9.3.5.2 Reduction in curve crash risk

Using this approach and the data in appendix section F.5, the predicted curve crash risk in the baseline was 80.4 crashes per 100 million curve entries. If the 85th percentile curve negotiation speed was to drop to the speed estimated from the curve geometry (the calculated 'safe' curve negotiation speed), the risk would drop to 45.4 curve crashes per 100 million vehicles entering these curves; a reduction of 43%. Under fixed ISA the risk was 78.2 curve crashes per 100 million vehicle entries – a reduction of 3%; under variable ISA, the risk was 66.8 curve crashes per 100 million vehicles entering the curve – a reduction of 17%. These results are summarised in table 9.5 and shown in appendix section F.6.

Table 9.5 Curve advisory personal crash risk

	Personal crash risk (curve crashes/100 million vehicle entries)	Personal crash risk reduction relative to baseline (%)
Baseline	80.4	-
Fixed ISA	78.2	3%
Variable ISA	66.6	17%
If travelling at 'safe' curve negotiation speed	45.5	43%

These potential crash reductions were applicable to those curves with posted advisory speeds. For the sake of simplicity and to ensure a conservative approach, these curve crash reductions were applied only to those crashes occurring on curves with posted advisory speeds.

Police-reported crash data, captured in the New Zealand Crash Analysis System (CAS) for the five-year period 2007–2011 (inclusive) is detailed in table 9.6.

Table 9.6 Police-reported injury crashes on rural speed limit roads 2007–2011 inclusive

Location	Injury crashes			Lost-control & head-on crashes on bend			Lost-control & head-on crashes on bend with advisory speed sign		
	Fatal	Serious	Minor	Fatal	Serious	Minor	Fatal	Serious	Minor
State highway	725	2640	10153	374	1185	3765	90	250	723
Local road	460	2173	6221	270	1268	3439	47	191	470
Total	1185	4813	16374	644	2453	7204	137	441	1193

An analysis of the data reveals that on rural roads (ie those with speed limits greater than 70km/h), loss-of-control or head-on crashes on bends accounted for:

- 54% of all fatal crashes
- 52% of all fatal or serious-injury crashes
- 46% of all injury crashes.

Of these bend-related lost-control and head-on crashes, 21% of fatal crashes, 19% of fatal and serious-injury crashes and 17% of all injury crashes occurred on curves where an advisory speed was signposted.

In order to determine the crash-reduction benefits applicable to the variable ISA system, firstly the overall crash reductions relating to changes in mean speed (determined in section 9.2.2.4) were applied to crashes that occurred outside of signed advisory curves. Secondly, the 17% injury crash reduction was applied to injury crashes that occurred on curves with advisory speed signs. These two values were then added. The results of this analysis are presented in section 9.4.

9.3.5.3 Issues

There are two further issues that will impact on the total crash-reduction benefits from ISA. First is the issue of compensatory behaviour under variable ISA; the second issue is that not all curves that should have advisory speeds signs do, and in some cases, those that do may not have the correct values.

The analysis of variable ISA showed that some drivers travelled at speeds higher than those recorded in the baseline (no ISA) scenario, and a number of these drivers reported feelings of being ‘pressured’ by following vehicles. An example of this can be seen in figure 9.7 between approximately distance 18,000m and 22,500m, where the variable ISA shows consistently higher speeds than the baseline when not travelling around a curve. This increase in speeds reduces the crash-reduction benefits from ISA.

While this may not be such an issue once there are higher levels of ISA penetration, it has been suggested that the distance over which the variable ISA curve speed warnings were activated in this trial may have been too long – the warnings began when the approach radius dropped below 800m and continued until the radius rose above 800m again, the exception being where there was a series of curves, in which case a change in the direction of the curve defined the start and end. Improving the HMI by reducing the distance over which the warnings are given, particularly downstream of the curve apex, may address this issue; and if the HMI is well calibrated so that it still warns drivers of unsafe approach and curve speeds, the benefits should not be reduced. If it is assumed that this issue will be addressed in any deployment of variable ISA in New Zealand and that there will be a high uptake of ISA, the expected benefits would be equivalent to using the crash reductions of fixed ISA to calculate the crash benefits from a mean-speed reduction (outside of curves), and to apply the curve crash-reduction benefits associated with variable ISA on curves.

Looking at the curve speed metrics of figure 9.8, some anomalies are apparent. For example the curve advisory speed on the first curve of A (curve 4) is higher than the estimated curve negotiation speed. The same issue applies to the second curve of A (although to a lesser extent), and to curve D. Conversely the advisory speed for both components of curve G is significantly lower than the estimated curve negotiation speed. Furthermore, looking at figure 9.7 it might be expected that a curve advisory would have been installed covering the curve at approximately 18,880m.

There are around 17,360 curves in the rural state highway network where the minimum radius within the curve is less than 400m. Over the five-year period 2007–2011 (inclusive), these out-of-context curves incurred 374 fatal crashes, 1185 fatal or serious-injury crashes, and 3765 of all injury bend-related lost-control and head-on crashes. While it is not possible to easily determine whether or not all of these curves have or should have advisory speeds, 9618 of these curves have a difference >20km/h between the calculated approach speed and the curve speed, suggesting they could be candidates for advisory speeds. Improving the coverage and values of curve advisory speeds would increase the potential benefits of variable ISA. An alternative would be to apply variable ISA to all of these curves, based on the calculated advisory speed, regardless of whether they are signed or not.[46]

The issue of disparities between the calculated advisory speed and the speed recommended by ISA would still need to be addressed, as they may impact on user uptake of ISA.

9.4 Benefits

9.4.1 Fixed speed limit ISA

Using the 'Simplified procedures for general road improvements' in the NZTA's *Economic evaluation manual* (EEM1) (2010), the crash benefits can be determined, as shown in table 9.7. Our crash benefit calculations assumed that the speed behaviour recorded during the experimental trials could be extrapolated to the general driving population and to other roads throughout New Zealand. This seemed reasonable, as the participants in this trial were selected to represent the New Zealand driving population (as explained in chapter 8). Similarly, it was assumed that the participants drove as they normally would and were not influenced by the fact that they were undertaking a trial – although there did appear to be a bias towards speed compliance in this study, with only 18.5% of drivers speeding under straight, 100km/h speed conditions, compared with national Ministry of Transport (2012) figures that suggest that 31% of drivers speed in similar conditions.

In order for the expected crash reductions to be applied across New Zealand, even though measurements were only taken in 50km/h, 80km/h, and 100km/h speed limit zones, the crash reductions were applied to all urban and rural roads (defining rural roads as those with >70km/h speed limits), and using crash history data over the last five years from 2007 to 2011.

The results of this analysis are shown in table 9.7, showing an overall annual crash-reduction benefit of $269 million dollars. Approximately two-thirds (62%) of these benefits were attributed to low speed limit zones (urban) and one-third (38%) were attributed to high speed limit zones (rural).

[46] Assuming that the benefits experienced on the curves in the trial apply to all curves with radii less than 400m.

Table 9.7 Crash-reduction benefits for fixed speed limit ISA

Road type	Annual accident cost savings ($M)
Urban	$166,609,717
Rural	$102,448,407
Total	**$269,058,124**

9.4.2 Variable speed advisory ISA

The crash-reduction benefits associated with variable ISA took into account both the change in mean speed and the speed reduction experienced on curves, as shown in table 9.8. These benefits were determined by applying the speed-crash risk reductions calculated for variable ISA (section 9.2.2.4) to injury crashes that occurred outside of signed advisory curves, and adding the benefits from applying the 17% injury crash reduction to crashes that occurred on signed advisory speed curves. Using the same methodology as applied in chapter 9.4.1 above, table 9.8 shows an overall annual crash-reduction benefit of $173 million dollars.

Table 9.8 Crash-reduction benefits for variable speed advisory ISA (as trialled)

Road type	Annual accident cost savings ($M)		
	From speed-crash risk	From speed reductions on signed advisory curves	Total
Urban	$105,432,719	Not assessed	$105,432,719
Rural	$35,920,144[a]	$31,701,630	$67,621,774
Total			**$173,054,493**

a) From speed-crash-reduction benefits occurring on roads not including signed advisory curves.

If it is assumed that issues associated with drivers speeding up when not on a signed advisory speed curve are resolved by improving the HMI of the device, and through a high level of uptake of ISA (which would reduce 'pressure' from other drivers), the speed-crash risk reductions from the fixed speed limit ISA can be used to give a benefit of $292 million dollars (table 9.9).

Table 9.9 Crash-reduction benefits for variable speed advisory ISA, assuming HMI and other issues are resolved (using fixed speed limit ISA mean-speed reductions)

Road type	Annual accident cost savings ($M)		
	From speed-crash risk	From speed reductions on signed advisory curves	Total
Urban	$166,609,717	Not assessed	$166,609,717
Rural	$55,553,829	$174,024,498	$125,687,667
Total			**$292,297,384**

Overall, this shows that there are significant benefits associated with both ISA typologies, with the variable ISA having either slightly higher (9%) or significantly lower (-36%) benefits than fixed ISA, depending on the assumptions used regarding how well variable ISA is implemented.

However, if the variable ISA system was expanded to cover all curves, and assuming the same level of crash reduction, the annual benefits of implementing variable ISA could be as much as $300–$396 million. However, a more realistic scenario may be to apply variable ISA to all curves where the curve radius falls below 400m, rather than all curves, in which case the benefits would fall somewhere between the two ranges calculated here.

The benefit calculation sheets are provided in appendix section F.7.

9.5 Costing

9.5.1 System outline

There are essentially three items required to implement an advisory ISA system:

1 a national speed limit management system or map

2 an in-vehicle device that provides the speed advice to the driver

3 a means for transferring the speed advice data to the in-vehicle device.

There are numerous deployment options available for the implementation of an advisory ISA system, and the option chosen will have a significant impact on the cost of implementing and operating the system.

Assuming that a GPS-based ISA system with a free-market organic-uptake deployment scenario is chosen, these implementation options range from users purchasing ISA devices, using 'smartphone' applications to provide ISA advice, or using other devices that have ISA functionality, such as in-car navigation devices and in-built devices that are part of the vehicle. These devices could include NZTA-approved devices that meet certain standards for accuracy and reliability, etc. Transfer of speed advice data can be done in real time over the cellular network; map updates can be broadcast periodically over the cellular network, or periodically downloaded by users.

The appropriateness of these options will also depend on the extent to which ISA is deployed. For example, if roadworks and other temporary traffic management speeds were to be included, then a system that updates in real time would be required.

9.5.1.1 Researched systems

- *New South Wales*: Much of the systems thinking underpinning the system described here was based on the systems currently developed in New South Wales. The New South Wales scene is subtly different from New Zealand, in that speed limit setting and management is the responsibility of the state authority – the local councils and shires submit their requests for speed limit changes through a web-based application system, and these applications are approved by the state. A similar system is envisaged for New Zealand, except in this country, approval would remain the responsibility of the RCA, and the New Zealand system for keeping track of speed limit changes would be expected to translate speed limit changes directly to a useful ISA map, which the New South Wales software system does not currently do.

  In New South Wales, the speed limit data is provided as weekly updates to an external party, which develops a new published map each quarter. (In return, the external party is allowed to use the map for other purposes and to on-sell it.)

  The map is then disseminated via the web to be uploaded to ISA applications developed for both Android and iPhones. There is no real-time data updating. Key costs associated with this system are:

  - the licensing agreement with the external party, which is believed to be less than $50,000 per annum (specific details are confidential)

- the development of the phone applications
- one 40% staff member to package and deploy the data.

The phone application is owned by the Transport Authority and provided free. With quarterly downloads via the web, the data costs are negligible. The New South Wales system has just passed its final legal milestone and will be deployed soon. At that time the user take-up and evaluation data will become available.

- *Alternative systems*: An alternative that is currently under development is vehicle-based sign recognition systems, such as Mobileye™ (www.mobileye.com), which have the ability to detect and recognise speed limit signs and potentially other signs such as speed advisory signs, pedestrian crossing signs, school zone signs, etc. These systems, which currently cost around $2000 (installed), are increasingly being fitted to top-of-the-range vehicle models, and could be a future alternative to map- and GPS-based systems. However, given the current cost, these were not considered as a viable alternative in this study.

9.5.2 National speed limit management system

As discussed in chapter 5, current speed limit setting and management in New Zealand is the responsibility of the individual RCAs. Each RCA must be able to provide this data to the public on request. In many cases this process is resource intensive. The creation of a national speed limit management system, should:

1 provide the capability to generate the national speed limit map

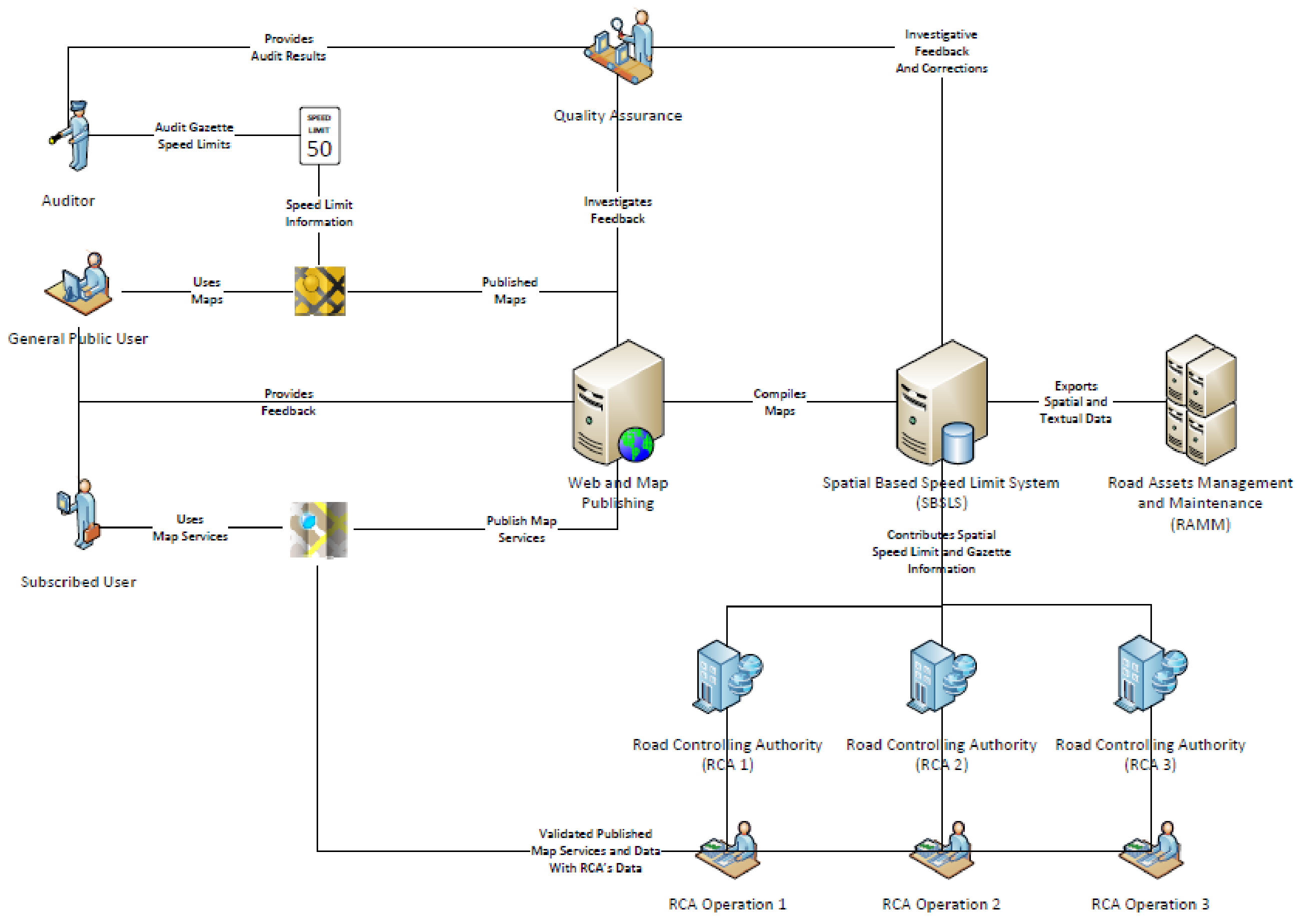
2 reduce the burden on RCAs of speed limit management.

The creation of a comprehensive speed limit map has been identified as an ‘enabler’ for a range of initiatives under the New Zealand Road Safety Strategy 2010–2020, *Safer journeys*, as well as supporting the CAS, road safety planning, and development of a nationally consistent speed limits as well as ISA.

Given the wider need for, and benefits to be gained from, a national speed limit management system and map, the creation and ongoing maintenance of this map could be considered a cost that is not borne by ISA. However, for the purposes of this assessment a cost has been included in order to show that the BCR was not sensitive to this development cost.

In the process of estimating the costs for the development of a spatially based speed limit management system, a number of assumptions regarding its functionality and the availability of speed limit data were made. In general, it was assumed that a simple system would initially be created. Figure 9.10 shows an example of how this might look.

Figure 9.10 An example of how the speed limit management system architecture could look



This system would store all national speed limit information, including variable speed limits and other related information such as Gazette notice references, for about 94,000km of roads (the New Zealand road network). Variable speed limits would include those on variable message signs and school zones, etc. However, as a real-time solution is not proposed at this stage, the speed limit management system would store details about the variable speed limit, and any ISA devices using the data would display the default speed limit in most cases, only changing for those speed limits that are activated at set times. The system that was costed would also include the following characteristics:

- It would be able to cope with differing speed limits by direction, and elevated roads for instances where roads are multilayered or three-dimensional.
- Themes would be used so that speed limit information for different vehicle classes and driver licences could also be made available.
- The system would be managed locally by each RCA, who would then publish their information to a national map service.
- It would be able to publish the data to a web service so that it could be viewed and downloaded by the public.
- The map services would also provide RCAs with a mechanism to audit the accuracy of their data by performing spatial and web services queries against the system.

- Data would also be exportable in a format compatible with RAMM. If speed limits were to be stored as a user-defined table in RAMM, then this would be relatively straightforward.
- It would be able to audit speed limit sign locations in relation to the gazetted speed limit zone boundary.

The costing assumed that:

- GPS map coordinates for all speed zone boundaries would be provided by the RCAs concerned at no cost
- RCAs would update their speed limit data over time as changes are made.

Applying these assumptions, it was estimated that a basic speed limit management system could be developed for approximately $170,000 (a cost breakdown is provided in appendix section F.8). A more integrated system with more functionality could easily cost double that or more. Therefore for the purposes of this assessment this cost has been doubled to $340,000.

There would be an additional cost associated with the data preparation and development costs for the development of a variable ISA. A value of $100,000 was allowed for this.

There would also be costs associated with the ongoing management of the system. It was assumed that a single custodian of the speed limit management database would be employed at 50% of their time to manage the system, undertake validation checks and publish the data to a map service. A value of $40,000 was allowed for this.

9.5.3 In-vehicle ISA device

The in-vehicle device that provides drivers with the applicable speed advice has two components:

- a GPS system that determines the location of the vehicle on the speed map
- an HMI that displays this information to the driver, along with visual and audio warnings when the driver exceeds the speed limit or curve advisory speed.

This functionality can be delivered either via a specific ISA device similar to that used in this trial, or via a 'smartphone' application.

A number of specific devices have an advisory ISA capability. These range from purpose-built ISA devices and software (such as the Dreevo2 with Speed Alert software used in this trial) to in-car navigation devices (such as the TomTom®) that include ISA functionality, and mobile applications (or apps) that can be downloaded from the internet and installed on a person's phone.

A large New Zealand electronic goods retailer[47] advertises navigation devices with speed limit alert functionality ranging from $119 to $499, with most devices costing around $200. An internet search found that several speed limit mobile applications[48] are available free of charge, with others ranging from the equivalent of about NZ$1 to NZ$5.

[47] Dick Smith store prices as of July 2012: Garmin Nuvi 2350 $179, Garmin Nuvi 40 $198, Garmin Nuvi 50 $197, Navman MY90XLT $347, Navman MY80T $199, Navman MY60T $178, Navman EZY45 In-Car GPS $198, Navman EZY15 $119, TomTom® Go Live 2050 $499.

[48] One example of a free app is Trapster (http://trapster.com/devices/android/), and an example of a paid-for app is Speed Limit, which costs about NZ$1 (www.amazon.com/wikiSPEEDia-org-Speed-Limit/dp/B004JOZJBI)

For the purposes of the benefit–cost calculation, it was assumed that an ISA device has a $200 purchase cost and that it has a five-year life span. It was assumed that there was no equipment cost associated with mobile applications, as it was assumed that the phone used to host the mobile application was purchased for other reasons.

9.5.4 Data transfer

Aside from the equipment purchase and replacement costs described above, the costs to users are the data transfer costs associated with updating the speed limit map stored on the device. Options include, but are not limited to:

- live update from a broadcast map over the SIM card in the device, where this map could be made available by the NZTA or a commercial provider
- manual download of map updates from the internet onto the ISA device
- choosing not to update the map on the device.

A real-time live continual download via broadcast system could allow speed advice to vary spatially and temporally to cover situations such as road works, queuing, school zones and the like. It was conservatively assumed that this type of system would require data transfer of about 10MB per month.[49] However, this could vary considerably, depending on the number and size of the updates. The cost associated with this would depend on individual user's mobile plan, and was estimated at $60 per user per year.[50] There is always the option for users to choose not to update the map on their device, in which case there would be no data transfer costs.

The alternative transfer mechanisms would be periodic web-based downloads. While this approach does not provide real-time data, depending on how speed limit changes are scheduled the currency of the data could remain reasonable. Internet costs for users to download map updates were not included as it was assumed that the majority of ISA users would already have access to the internet and that as the file size of maps is small, this would not significantly impact on users' internet data usage or costs.

Traditionally there are also costs associated with the map updates themselves. These range from free sources, such as WikiSpeedia, which is an open-source system updated by users, to more expensive providers such as TomTom®, who charge $128 for a New Zealand map update to a TomTom® 550. A portion of the map update cost is associated with the cost to the provider of obtaining speed limit data. So, if we accept the scenario of the NZTA developing a speed limit management system and making speed limit maps available free of charge, provided there is compatibility with the majority of ISA devices, almost all users could access map updates free of charge.

9.5.5 Other cost considerations

There are a number of other cost considerations that could have a significant impact on the cost of the development and operation of an ISA system. Possible additional costs include:

- costs to make the data available, such as web hosting and high-speed internet connection, including costs associated with broadcasting map updates over the cellular network, which would require a high-grade internet connection and servers that could handle the load – this could be a significant cost

[49] Based on experience in Australia, sourced from phone conversations with staff at Smart Car Technologies Pty Ltd.

[50] Based on a $0.5 per MB casual mobile internet rate offered by New Zealand mobile phone operator, 2degrees.

if, for example, each user transferred 10MB per device per month, with 100% penetration to the 2.8 million licensed motor vehicles in New Zealand[51]

- the cost of hardware such as servers associated with the storage of data, which are expected to be negligible for the system proposed, or which could be in the order of several thousand dollars if users' speed data was to be logged
- development costs for any 'smartphone' apps that might be developed
- costs associated with creating maps from the speed limit database that are compatible with different ISA devices – this is similar to the cost associated with the licensing agreement that the New South Wales RCA has with an external party (see section 9.5.1.1)
- costs associated with developing a set of standards for ISA devices and for assessing and approving commercial ISA devices.

For this assessment these costs were broadly covered by allowing for a $100,000 start-up cost and a $20,000 annual maintenance cost after that.

9.5.6 Cost estimation

As noted above, the cost of implementing an advisory ISA in New Zealand varied considerably depending on the options chosen and the costs considered attributable to ISA.

For example, if the cost of developing a national speed limit management system was excluded, and if it was assumed that drivers would choose either the cheapest option (free 'smartphone' app) or use a pre-existing navigation device, and that speed limit maps were available free of charge, then the cost of implementing an advisory ISA would almost be nil.

For simplicity, it was assumed that any initial roll-out of an advisory ISA would not include real-time information (such as traffic information and other live updates), as this would significantly increase data and server costs as well as the complexity of the system. For this reason, and due to potential privacy or 'big brother' concerns, it was also assumed that no data would be logged.

For the purposes of this study, the costs shown in table 9.10 were included.

[51] Including cars, rental cars, taxis, buses and coaches, trucks – sourced from *New Zealand motor vehicle registration statistics 2011* (NZTA 2012).

Table 9.10 ISA deployment cost summary

Item	Cost ($)	Comment
Initial fixed costs		
Development of a speed limit management system	$340,000	This cost is highly dependent on the form of the system chosen, and the estimate for a simple system costing $170,000 has been conservatively doubled
Initial IT-related costs	$100,000	
Development of variable speed advisory ISA system (additional to fixed speed limit ISA costs)	$100,000	
Regular costs on a five-year cycle		
In-vehicle ISA device	$560,000,000	$200/user for 2.8 million users, with initial map
Annual costs		
Map updates	$112,000,000	$60/user for 2.8 million users, assuming all users choose to receive updates over the cellular network at 10MB/month
Speed limit management system custodian	$40,000	
On-going IT-related costs	$20,000	

Table 9.10 shows that while the costs per user may seem low, they are significant once they are factored up for the New Zealand driving population.

These costs did not take into account growth in the vehicle fleet, as any growth in the fleet would almost certainly be swamped by the increase in ISA capabilities integrated into vehicles and an increase in the use of 'smartphone' apps. It is important to note that no reduction in cost with time was assumed. However, there is evidence that such costs decline dramatically over time, typically to 10% of the original cost within 10–20 years. As such, these costs could be considered to be conservative.

9.6 Benefit–cost analysis

A range of scenarios were considered to give an idea of the possible range in BCRs for implementation of an advisory ISA system.[52] The costs used were conservative estimates.

Table 9.11 shows that when all of the costs included in table 9.10 were considered over a 30-year analysis period, the total present value of these costs was very high; over three billion dollars in each case, which resulted in BCRs of between 0.6 and 1.1.

[52] Using the 'Simplified procedures for general road improvements' in the NZTA's EEM1 (2010), which uses a 30-year analysis period and an 8% discount rate.

Table 9.11 BCRs including all costs, for advisory ISA applied to all potential users in New Zealand

	Fixed speed limit ISA	Variable speed advisory ISA applied to signed advisory curves		Variable speed advisory ISA applied to all curves	
		As trialled	With improvements	As trialled	With improvements
PV benefits ($M)	$3211.7M	$2070.1M	$3526.1M	$3781.7M	$4931.7M
PV costs ($M)	$3437.7M	$3437.8M	$3437.8M	$3437.8M	$3437.8M
BCR	0.9	0.6	1.0	0.9	1.1

If it was assumed that half of users would opt for a free ‘smartphone’ app[53] instead of a $200 ISA device, and that only half of users would choose to receive live updates over the cellular network, the costs were almost halved, to give BCRs of between 1.2 and 2.9 (table 9.12).

Table 9.12 BCRs including all costs, but assuming 50% use of free ‘smartphone’ apps and 50% use of free map downloads, for advisory ISA applied to all potential users in New Zealand

	Fixed speed limit ISA	Variable speed advisory ISA applied to signed advisory curves		Variable speed advisory ISA applied to all curves	
		As trialled	With improvements	As trialled	With improvements
PV benefits ($M)	$3211.7M	$2070.1M	$3526.1M	$3781.7M	$4931.7M
PV costs ($M)	$1719.5M	$1719.4M	$1719.4M	$1719.4M	$1719.4M
BCR	1.9	1.2	2.1	2.2	2.9

This illustrated how sensitive the cost, and hence the BCR, was to any costs to the user. Any central development or maintenance costs were very small in comparison, even though generous estimates were allowed for these costs.

An alternative approach, which could be used to aid the decision of whether to invest in the deployment of an advisory ISA system, would be to use zero user costs, as users will only take up an advisory ISA system if they are willing to.[54] The decision as to whether an investment should be made in ISA would then become reliant on the uptake of ISA, as this would influence the crash benefits realised.

Table 9.13 shows that to achieve BCRs of 1.0 or greater, a user uptake of only 0.06% would be required when considering the assumed costs to central government of deploying an ISA system, and assuming benefits decline linearly with user numbers.

[53] Assuming a ‘smartphone’ app is just as effective as a specific ISA device.

[54] As these users would be self-selecting there is a chance that if only those who are concerned about speed-containment use these devices, the benefits derived from these users may be less than the benefits found in this study, which sought to use a representative sample of the driving population. This issue was not addressed in this study.

Table 9.13 BCRs including all central development and maintenance costs but no user costs, for advisory ISA applied to all potential users in New Zealand

	Fixed speed limit ISA	Variable speed advisory ISA applied to signed advisory curves		Variable speed advisory ISA applied to all curves	
		As trialled	With improvements	As trialled	With Improvements
User uptake (%)	0.06%	0.06%	0.06%	0.06%	0.06%
PV benefits ($M)	$1.9M	$1.2M	$2.1M	$2.3M	$3.0M
PV costs ($M)	$1.1M	$1.2M	$1.2M	$1.2M	$1.2M
BCR	1.8	1.0	1.8	1.9	2.5

Table 9.14 shows that with a user uptake of just 0.5%, BCRs of between 9 and 21 could be achieved.

Table 9.14 BCRs including all central development and maintenance costs but no user costs, for advisory ISA applied to all potential users in New Zealand

	Fixed speed limit ISA	Variable speed advisory ISA applied to signed advisory curves		Variable speed advisory ISA applied to all curves	
		As trialled	With improvements	As trialled	With Improvements
User uptake (%)	0.5%	0.5%	0.5%	0.5%	0.5%
PV benefits ($M)	$16.1M	$10.4M	$17.6M	$18.9M	$24.7M
PV costs ($M)	$1.1M	$1.2M	$1.2M	$1.2M	$1.2M
BCR	15	9	15	16	21

9.7 Discussion

The analysis in this report shows that there could be considerable benefits associated with the deployment of an advisory ISA system in New Zealand. The crash reductions predicted ranged from 1% to 22% for the different crash severities, road types and ISA conditions considered. These equated to annual benefits of $269 million for fixed ISA, and annual benefits of between $173 million and $292 million for variable ISA. If the variable ISA was applied to all curves with radii 400m or less, the benefits would be substantially greater, ranging from up to $300 million to $396 million. Further study would be required to determine whether the benefits found in this study on signed advisory curves can in fact be transferred to all curves with radii of 400m or less. These calculations also assumed that users would use the ISA device all of the time. Further study would be required to verify the level of use of the device.

These benefits would be reduced for a less-than-100% uptake of advisory ISA. If the benefits were attributed to ISA users and divided equally amongst the 2.8 million licensed vehicles in New Zealand, this would equate to between $51 and $117 per user per year.

The fixed costs to central government of deploying an advisory ISA system in New Zealand are exceptionally low in comparison to the benefits, so even if these costs are much higher than estimated here, it would not significantly affect the BCR. The BCR is much more sensitive to changes in user costs.

The costs to users of purchasing ISA devices and updating their map data are voluntary costs, with users able to choose whether to spend their money on ISA and also which option suits them best (ie live data transfer or free map download). It could that most users will choose to use ISA to reduce the chance of getting speeding fines and to reduce the burden of the driving task. If this is the case, then it could be argued that user costs should not be considered to be borne by ISA. This has a major impact on the BCR, taking if from 0.6 to 2.9 for the 100% uptake scenarios considered, to requiring only 0.5% uptake to achieve BCRs of 9 to 21 under the scenarios considered.

Given the preceding points, and the fact that it is difficult to define the costs to cover the likely range of implementation scenarios and uptakes, the benefit-cost analysis presented in this report is only intended as a rough indicator. The main focus of this report was on quantifying the benefits as a means of assessing whether the effort and resources required to deploy an advisory ISA system in New Zealand would be worthwhile. Given the benefits described above, this certainly appears to be the case.

It would, however, be prudent to undertake further work to obtain robust cost estimates for the deployment of an advisory ISA system in New Zealand, and to confirm the benefits.

9.8 Recommendations

As a result of this benefit-cost study, the following steps are recommended:

1. Further investigation into the deployment of an advisory ISA system in New Zealand should be undertaken, as it could carry potentially significant benefits at potentially little cost to central government. The deployment of advisory ISA would still be economically viable even with very low levels (<1%) of uptake.
2. Further work to inform decisions around the preferred deployment scenario, and to fully scope the development of an ISA system and all of the associated costs, should be undertaken.
3. Further study should be undertaken to fully understand the potential additional benefits of an ISA system that includes advisory curve warnings as well as speed limit information, and to understand any adverse effects, such as compensatory behaviour, so they can be eliminated. This should include consideration of the curves to which advisory ISA would be applied (ie only signed advisory curves, curves that are less than a certain radius, or all curves) as well as work with focus groups to understand the user acceptance implications of having curve advisory speeds in ISA that may be different from the signed curve advisory speed.
4. A study should be commissioned to address the apparent inconsistency in advisory curve signage that occurs over the national road network – this could include adapting existing predictive models or developing new models to allow theoretical calculation of advisory speeds for signs, rather than relying on ball-bank gauge measurements, which can be susceptible to human error.

10 Advisory ISA – institutional barriers

10.1 Introduction

The final set of barriers that restrict the uptake of ISA technology are institutional and political. This section involves reviewing the relevant international literature and working with local and central government and the motor industry to identify potential institutional, regulatory or other barriers to the introduction of an advisory ISA system in New Zealand. The majority of barriers to the introduction of ISA systems are related to user acceptance, and as stated by Vander Pas et al (2012), 'the more intervening ISA is, the less accepted it will be'.

By virtue of its non-directive nature, advisory ISA is therefore not as subject to the institutional and other barriers that confront more directive forms of ISA. Jamson et al (2006) intimate that the main barriers to the introduction of ISA systems are now public acceptance and political will, with cost having receded as a barrier as technology has improved and its real cost reduced. Less public acceptance leads to more reluctance by policymakers and politicians to institute a system. Carsten (2009) elaborated on this and stated that the public had yet to be won over, and it was time for politicians who expressed a road safety commitment to take the lead. He expressed similar sentiments in his 2012 paper, where he also cited the absence of a digital road map containing accurate and up-to-date information on speed limits as a significant obstacle to overcome. This is a matter that is currently being addressed with priority by the NZTA.

In the case of advisory ISA, focus groups for this project found that in general, drivers were resistant to ISA, particularly those in the 24–64 year age group, meaning that were it to be introduced officially, some level of marketing would be required.

Notwithstanding this problem with public acceptance, relatively few concerns were voiced by stakeholders. However, significant regulatory and infrastructural activity is necessary to implement any system on the road network in New Zealand.

Advisory ISA systems display the speed limit to the driver and indicate changes in the speed limit, while providing the driver with feedback when they exceed the posted speed limit. Such systems can also incorporate variable speed information, such as curve advisories. The key difference between advisory ISA and other ISA systems is that it is up to the individual driver to make decisions regarding that advice. In addition, for most systems no information is transmitted to any external party.[55] In general, the literature considers advisory ISA as a 'benign' option with little evidence of barriers to use; however, some studies have reported some resistance.

Although ISA trials have been undertaken in areas of Europe, Japan, Canada, China and Australia, actual routine deployment of ISA technology has been sparse. Vander Pas et al (2012) produced the following table regarding the most important uncertainties related to implementation of 'warning' ISA (or in our case, 'advisory' ISA).

[55] Data logging by an external party is possible for ISA devices that have a SIM card installed and activated. This is generally under the control of the user, who can choose to remove or deactivate the SIM card.

Table 10.1 Uncertainties related to implementation of 'warning' ISA (Source: Vander Pas et al 2012)

Uncertainty	Warning		
	Rank	Mean	Standard deviation
Uncertainty regarding the technical characteristics and updating of the speed limit database	1	2.70	1.05
Uncertainty regarding the liability allocation in case things go wrong with the functioning of ISA	2	2.43	1.07
Uncertainty regarding the factors which contribute to ISA acceptance of car drivers and the degree to which each of these factors contributes to the level of acceptance	3	2.33	0.85
Uncertainty regarding the willingness of people to use ISA	4	2.29	1.00
Uncertainty regarding which stakeholders are involved in implementing ISA and the importance of each of the stakeholders for ISA implementation	5	2.21	1.05
Uncertainty regarding the effect of different ISA implementation strategies on ISA implementation (eg voluntary implementation, giving incentives, mandatory implementation)	6	2.20	0.97

The uncertainties described in table 10.1 were gleaned from a survey of 163 'experts' in the field of ISA. These people were authors of papers on ISA (133) and 33 others were recruited by asking the authors for suggestions of others to be contacted ('snowball method'). The levels of uncertainty pertain to the following scale from Walker et al (2003, p3).

1 Fully determined – there is no uncertainty regarding the subject (ie there is perfect understanding of the subject).

2 Statistical uncertainty – there is a lot of information about things that can happen and their likelihood. (ie there is a vast amount of empirical information on the subject).

3 Scenario uncertainty – it is understood how the main mechanisms work; the range of things that can happen is known, but they cannot be ranked because the likelihood is unknown (ie we have limited information on the subject).

4 Recognised ignorance – there are some clues regarding the subject, but it is known that there are still things that are unknown (ie there is little information on the subject).

5 Fully uncertain – there is no clue about the subject and there is no knowledge about what can happen (ie there is no information on the subject).

These ranks are the top five ranks, based on mean uncertainty scores; the larger the score, the more uncertainty. For all the factors mentioned, the mean ranks were in the area between 'statistical uncertainty' and 'scenario uncertainty'. For more-restrictive types of ISA the uncertainty scores for the factors were higher, and more-restrictive options were always higher in their scores than less-restrictive options.

All of the uncertainties listed in table 10.1 have face validity as barriers. They are all the types of uncertainties that encourage caution among policymakers and politicians and would affect how politicians and institutions react in terms of future ISA policy, ISA implementation tactics and the type of legislative backup required. Any of these things, if not well managed, could result in blockages in the implementation of ISA. Further details are contained in appendix E.

10.2 Options for advisory ISA

There are various ways in which advisory ISA can be promoted, ranging from 'do nothing' to 'compulsion'. These options, along with their pros and cons, are discussed further in the following sections.

10.2.1 Do-nothing approach

The do-nothing approach means allowing the current proliferation of GPS-based vehicle navigation systems to continue. These devices provide information about the speed limit, and some devices advise the driver when their speed, as measured by the device, is inappropriate. Over time it is expected that more drivers will utilise these devices. There appear to be no institutional or regulatory problems with this approach.

10.2.2 Encouraging use without any marketplace intervention

Under this option, encouragement would involve social marketing campaigns to encourage use, but with no overt interference in the market for devices, nor any specific setting of standards for devices apart from the normal requirements related to vehicle equipment and electronic devices. This should have no more impact than the do-nothing approach, apart from the costs of the 'encouragement'. The social marketing would need to be carried out carefully so as to avoid encouraging drivers to be overly optimistic regarding the accuracy of their devices, thus putting themselves at risk of police apprehension.

10.2.3 Encouragement augmented with regulatory/legislative provision

Another way forward for advisory ISA would be the 'encouragement option' combined with some legislative requirements to hone the impact of the devices. These requirements would differentiate 'approved ISA devices' from other guidance/GPS systems, which may still be allowed but would not carry the stamp of approval.

Use of an approved device would carry incentives based on the lowered speed-related crash risk of users. These might be reduced insurance premiums, similar to the reduced premiums associated with use of vehicle immobilisers. Based on previous research and the results of the focus groups, the use of insurance premium reductions as an incentive could be very successful for increasing uptake, particularly in high-risk groups such as drivers who are under 25 years old.

The rest of the discussion in this chapter assumes that some sort of 'augmented encouragement approach' would be used, which would require legislative and other actions if it was to be successful.

10.2.4 Legislative actions under an augmented encouragement approach

This section outlines the legislative requirements that could be considered when taking an augmented encouragement approach to improve the quality of advisory ISA devices introduced. Devices labelled 'discretionary' would be augmentations of the basic ISA, which would provide speed limit information only. Those labelled 'non-discretionary' would be required, whatever the ISA system used. This discussion assumes that enough devices would already comply (or manufacturers would be willing to make them comply) with the legislative actions outlined below, to make these legislative changes viable. If this was not the case, then any of these legislative actions could become a major barrier to implementation. One option to overcome such a barrier could be for a customised device to be commissioned; however, this would obviously represent a potentially significant cost.

10.2.4.1 Requiring warnings to drivers exceeding the speed limit (discretionary)

In addition to providing speed limit information, this action would require all GPS devices to warn drivers when they are exceeding the speed limit. Accuracy standards for device performance (such as requirements on the accuracy of the GPS in the device) would need to be set, as this action has the potential to cause conflicts with police enforcement unless treated very carefully in legislation. For example, if a GPS-based system were to be used, speed limit mapping may not be perfect. Thus the speed limit advice from the device to the driver might not be as good as that available to the police when they decide where to place their speed enforcement vehicle.

It is therefore possible that a perfectly legitimate speeding ticket could be issued to a person who is violating a speed limit but who has not yet been told by his ISA that he is doing so. It could, of course, be argued that the driver's responsibility to look at the road signs takes precedence over any ISA information, but any uncertainty over responsibility would need to be addressed in the legislation. The frequency of such an event happening would depend on such factors as the accuracy of the speed limit maps used by the ISA system, and if GPS is used to identify the change in limit, how accurate the GPS is in pinpointing where the limit changes. If a transponder or beacon-type system is used, the same sort of conflict between enforcement devices and the beacon-based system could arise.

Comments from the police indicate that they would have issue with any system where a GPS-derived speed display in the vehicle was promoted as being accurate (given that GPS uses averages to determine speed and might vary from radar). This being the case, a solution could be that any warning system is set up so that it works conservatively; ie has no possibility of not giving a warning if the vehicle is exceeding the speed limit. This is broadly similar to the way speedometers are set up to work now. For example, if a device has a maximum speed measurement error of a certain percentage, then the speed displayed by the device could be set slightly higher than that percentage above the measured speed.

10.2.4.2 Requiring the devices to use specifically developed speed databases (non-discretionary)

This action would require all devices to use data from a specifically developed speed limit database, which could include requirements for live updates. This would mean that all devices would need common compatibility with the database and connectivity so that the live updates could take place. Such a measure would require standards-setting action by the appropriate authority; an exercise that would be broadly similar in nature to that required to put together the common public transport fare payments system currently being introduced in Auckland.

10.2.4.3 Human–machine interface (HMI) requirements for GPS accuracy (non-discretionary)

This action would require the HMI on GPS devices to display when the GPS signal is lost, when GPS accuracy is outside of a certain range, or when speed limit map updates are not being received. This action would act as a safeguard and prevent the display of incorrect driver speed and/or posted speed limits.

Introducing these requirements would require the setting of standards, both for the device and for the GPS, but would be a simpler exercise than the previous action as no commonality of display format between devices would be required. If commonality of display format was required the complexity of standards would need to increase.

10.2.4.4 GPS accuracy and coverage (non-discretionary)

It would be an unfortunate outcome if the situation outlined in the previous section was a common occurrence. Thus standards would need to be set for GPS accuracy and coverage to reduce the occurrence of events where the display of inaccurate information would need to be suppressed by the device to acceptably low levels. It would also be an advantage if the devices are able to record locations and technical details of unsuccessful performance, so that corrective action can be taken. Chapter 6 of this report, which covered these areas in depth, showed that it would be reasonable to roll out an ISA system based primarily on a consumer-grade in-car navigation system, with consideration given to installing transponders in locations where GPS coverage is particularly poor. Further recommended research includes:

- testing the directional accuracy of GPS coverage in a moving vehicle
- testing the effect of elevation on the positional accuracy of GPS coverage with only three satellites
- investigating the 'filters' used by different manufacturers for in-car navigation units
- repeating the field tests over multiple days with different GPS brands to build up a statistically viable database for analysis
- undertaking field tests of GPS coverage in locations known to have particularly poor GPS coverage.

The necessity for this research and standard setting is a barrier to implementation.

10.2.4.5 Compulsory fitting of advisory ISA devices (discretionary)

This action would make the fitting of advisory ISA devices compulsory on new vehicles and perhaps used imported vehicles, and might include a retrofit on all vehicles.

This action would have severe regulatory, cost and political implications, all of which would act as barriers to the implementation of an ISA-based system. Used-vehicle importers would be likely to oppose such a move and they have signalled that they would like early input into any government proposals to introduce such a requirement. New-vehicle importers, while supportive of voluntary introduction, have also signalled that they would want to have input into any regulatory controls. There is a risk that the involvement of vehicle importers, who are likely to be opposed to compulsory fitment of ISA devices, could result in the 'watering down' of the effectiveness of the system.

There would also likely be opposition from the general public regarding the additional costs involved, and such a move would also negate the possible benefits from incentives such as insurance premium discounts for ISA users.

10.2.4.6 Storage and accuracy of speed limit data (non-discretionary)

Accuracy of speed-limit-mapping data is an important police concern and essential to the operation of any officially sanctioned ISA system. Regulatory action related to the recording, storage and accuracy of speed limit information would be required. Speed limits are currently recorded, by zone, in registers by exception. As outlined in chapter 5, a review of the speed-limit-setting framework may be required to ensure that the way speed limits are referenced (as required in legislation) can be easily transferred to a geospatial location. Similarly, a change in the Traffic Devices Rule regarding the location accuracy of speed limit boundaries may be required. Speed limit location accuracy would be a topic requiring action, including:

- specification of the accuracy required in delineating speed limit zones in the register/map, including guidance on how to measure the distance to the start/end points of speed limit zones
- a requirement to record GPS coordinates of the start/end points of speed limit zones (including accuracy requirements)
- clarity over whether the location description or the GPS coordinates are the primary and secondary location descriptors

- a requirement to audit or otherwise demonstrate that the speed limit sign location is within 20m of the gazetted speed limit zone
- a requirement to audit the speed limit register/map to ensure that speed limit zones accurately reflect the gazetted locations.

10.2.4.7 Importability of data into a national system (discretionary, but highly advantageous)

In addition, if a national mapping system is decided upon there would need to be provisions made so that data from throughout the country could be directly imported into the national system.

10.2.4.8 Issues related to the speed information from the various devices in the vehicle (non-discretionary)

Issues related to the speed information from the various devices in the vehicle would have to be addressed. It has been suggested there may be issues relating to the speed shown on speedometers versus the speed shown by ISA units (from GPS), or the speed taken from the vehicle's anti-lock braking systems (ABS) for in-built ISA systems. These systems may provide conflicting speed information to that provided by police speed enforcement equipment such as speed cameras and lasers.

Speedometer accuracy is currently covered in Land Transport Rules, where the only requirement is for it to be 'in good working order'. This means that it works and complies with vehicle standards. In New Zealand, vehicle equipment standards are based on the acceptance of the main overseas standards of developed countries or blocs where vehicles are manufactured. Therefore we may need to accept the standards of Australia, the US, Japan and the UNECE regulations. According to the AA:

> *… manufacturers generally base speedometer requirements on the UNECE regulations, and these state that speedometers cannot give a reading below the actual speed, but may overestimate by up to 110% – plus an additional 4km/h. Thus, vehicle speeds may indicate up to 92km/h when one is only going 80km/h. In the USA, the standard stipulates only up to 105% over-reading* (http://aadirectionsblog.aa.co.nz/post/Speedometer-Accuracy.aspx).

For people with ISA systems that warn when speed is becoming illegal (or any other system that gives speed information to the driver), the information will differ from the overestimated speed from the speedometer, just as roadside speed information radars currently differ from speedometer information. There is no known problem at present with speedometers overestimating speed and it is hard to envisage any detrimental impact it would have on ISA. A detrimental impact on ISA would only logically happen if speeds were underestimated by speedometers, which should never be the case in New Zealand.

Assuming any speeds displayed by ISA are accurate within a legislatively defined tolerance,[56] the only possible downside of widespread application of ISA would be that drivers, whether they use ISA or not, would over time become aware of their speedometers overestimating speed and might make ad-hoc upward adjustments to their speed. This in turn might produce an adverse effect on safety, which would be very hard to detect or quantify. Such an outcome would be a perverse unintended consequence of ISA, and would be hard to prove one way or the other.

ABS typically employs 'Hall effect' speed sensors. These speed sensors are used at each front wheel and either a single-speed sensor for both rear wheels or individual speed sensors at each rear wheel. The speed sensors are monitored by a dedicated electronic control unit (ECU). The system controls the front brakes individually and the rear brakes as a pair.

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[56] It is possible that authorities might consider building in some form of overestimation buffer, as with speedometers.

In a panic-braking situation, the wheel speed sensors detect any change in wheel speed. The ABS ECU calculates the rotational speed of the wheels and the change in their speed, then calculates the vehicle speed. The ECU then judges the slip ratio of each wheel and instructs the actuator to provide the optimum braking pressure to each wheel.

From the above discussion of ABS, it is clear that speed provided by in-built ISA, which interrogates ABS, is likely to be of similar or better accuracy than that provided by the vehicle's speedometer.

In conclusion, however the speed used by the ISA device is provided, it needs to be undertaken in such a way that it does not contradict the measurements from police equipment, as any conflict here would degrade the usefulness of ISA devices to consumers. Police equipment is rigorously calibrated and certified by ESR and the acceptable devices are specified by Gazette notice. The existence of the Gazette notice and the carrying out of the calibration means that police readings are acceptable in court as evidence of vehicle speed. There would need to be interagency negotiations about how these issues would be tackled and what legislation or rule making would be required to ensure that conflicts in terms of evidential use of readings from the different sources do not occur. As mentioned earlier, a solution could be to make speed warnings given by ISA systems conservative, as speedometer readings are now. This would appear to cover the police concerns mentioned earlier.

It is also readily apparent that most drivers would seek to resolve any anomalies between ISA-provided speed reading and the vehicle speedometer reading. Therefore, take-up of ISA will require access to facilities for checking both speed and calibrated 1km distances for checking GPS output. Not only will there be a need to increase the availability of these facilities, but also the AA and roading authorities will have to better promote where they are sited so that the motoring public will know where to access them.

10.2.5 The costs of the scheme

Other than the do-nothing option, all other schemes available have a cost, such as the infrastructure, database, and development and legislative overhead needed, in addition to significant promotional expenditure. Benefit–cost analysis is part of this project; however, such analyses are a tool for comparing different projects on the basis of the ratio of their benefits to their costs. It does not take into account the government's absolute ability or willingness to pay the costs of the project, considering other competing demands on its finances. Compulsion would also involve a cost to the motorist. These costs constitute an obstacle. Even under a voluntary uptake scenario, users' willingness to pay is a barrier to uptake, particularly in the short term, as access to low-cost or free ISA technologies is limited to users who have already adopted 'smartphone' technology.

10.2.6 Insurance premiums

It would seem that acceptance of ISA's road safety benefits is increasing in the insurance industry. The Transport Accident Commission (TAC) Victoria's no-fault motor vehicle injury insurer has shown its commitment by funding the mapping of Victoria's speed limits to facilitate the use of ISA.[57] Because of these safety benefits it is thought that vehicle insurance companies might offer a reduction in insurance premiums based on the kilometres for which an advisory ISA system has been activated (eg Hess et al 2009). Thus in this case, an incentive rather than an impediment is likely.

[57] www/theage.com.au/digital-life/cartech/gps-tool-to-warn-speeding-drivers-20100113-m6zg.htm Accessed 14 May 2012.

10.2.7 Warranties

As with the after-market installation of GPS-based vehicle navigation systems, installation of advisory ISA systems (being effectively a superficial add-on) would not interfere with any of the vehicle's critical systems and consequently would be unlikely to affect vehicle warranties.

10.2.8 Privacy issues

As long as systems are provided with the correct safeguards, there appear to be no privacy or freedom-of-choice issues with advisory ISA systems. However, public perception rather than reality would be the crucial factor as to whether these sorts of systems garnered political support. The focus group study that was conducted as part of this research revealed that privacy and 'big brother' connotations were of concern to members of the general public; regardless of whether this is a correct or incorrect perception, privacy concerns do need to be addressed for general uptake to be successful. Any system must also be set up so that there is no transmission of data identifying individual vehicles to government agencies, notwithstanding the potential for such transmission of data by devices.

There may need to be some legislation and adjustments to hardware and software to ensure that this is the case. If it is not legislated against, central collection and storage of information could occur, and may be acceptable if it is held in a de-identified manner. Currently, the e-ruc[58] system successfully carries out the management of the electronic collection of road user charges, using GPS-based vehicle trackers with controls both at the device level and at the central level. This system is set up to allow the identification and subsequent apprehension of offenders by the police; however, as Goodwin et al (2006) remarked, it must be emphasised that the use of ISA technologies does not require any central control or collection of data from individual vehicles. The flow of information is in the opposite direction – from the centralised speed map data to the vehicle. The alternative of more widespread enforcement action is potentially much more intrusive.

Given that they already do so with their own navigation systems, it is likely that businesses such as haulage companies would collect information on their drivers. There would need to be a well-defined mechanism for formalising consent to this by the drivers. Policies and protocols would need to be set up to cover the situation of possible court subpoena of data for evidence (refer to section 10.2.10).

10.2.9 Legal liability issues related to possible over-reliance on devices

When asked as part of this research, the Ministry of Transport made the point that a range of safety-based ITS devices may transfer the responsibility of the driving task away from the driver towards in-vehicle and network-based devices on which the driver may over-rely. This was also a concern of some of the focus group participants in this study, particularly in the 25–64 year age group, who considered the device to be 'spoon feeding'.

However, as the European Transport Safety Council (ETSC) remarks (Goodwin et al 2006):

> *ISA does not mean that complete control is taken away from the driver. The driver is still responsible for the control of the vehicle and ISA technologies are merely a tool to enable the driver to comply with the speed limit* (p10).

[58] www.nzta.govt.nz/resources/road-user-charges/eruc-guidelines/ Accessed 14 May 2012.

and

> *ISA technologies intervene in the driving task to a varying degree. With most types, the intervention is no more than what drivers currently encounter from devices such as ABS, ESP [electronic stability program], lane-keeping support, cruise control, distance warning, etc. Many of the handling and engine management packages currently on offer intervene in some way between the driver and the controls of the vehicle. With all these devices, the driver still remains in control of the driving task. This is also the case with ISA technologies* (p11).

Previous research has also found that drivers subjectively rate the cognitive workload of driving with an ISA device as the same as driving without one, suggesting they do not remove themselves from the driving task when using the device (Comte 2001).

In addition, it should be emphasised that the advisory ISA system does not take any control over the vehicle, but compulsory ISA systems could be introduced that do. As it can take over the driving task, this type of device may have larger legal implications that would need to be considered separately.

10.2.10 ISA data as evidence in crash or driver behavioural investigations

Data from logs associated with advisory ISA systems could potentially be used for crash investigations, for investigations of driver behaviour for research purposes, or in court by subpoena. Appropriate legislative provisions would need to be in place to cover this eventuality, according to the position of the government of the day on using such information for such purposes. However, this is little different from the possibility of using data already gathered by many in-vehicle computer systems, as is already done in motor vehicle crash reconstructions.[59] Ownership of and access to this data, however, is another issue.

10.2.11 The impact of ISA on the need to provide speed limit information

Modern speed-limit-setting methods delegate speed limit setting more to RCAs, and also seek to tailor speed limits more closely to the character of the road than in the past. These new methods have resulted in an increase in the number of speed limits in operation, resulting in concerns being expressed by drivers who feel it is sometimes difficult for drivers to 'know for sure just what the speed limit is' and that the signage is inadequate. A well-constituted ISA with access to accurate speed maps would go a long way towards allaying these concerns and may provide an alternative to sometimes expensive and intrusive solutions, such as more repeater signs. This could be as simple as a downloadable ISA 'smartphone' application. Such a system is being trialled nationwide in Australia (www.speedalert.com.au/whereis.php), using a private speed limit database. The app is currently compatible with a small number of smartphone operating systems, but development of apps for a wider range of smartphones is proceeding. Recently the Transport Accident Commission (TAC) in Victoria has provided a state-wide speed limit database that can be freely used by any ISA or navigation system provider, including mobile-phone-based applications (www/theage.com.au/digital-life/cartech/gps-tool-to-warn-speeding-drivers-20100113-m6zg.html). Carsten (2009) suggests that if ISA was ubiquitous in the car fleet, new speed limits (eg 30km/h) could be delivered for virtually no cost, as in his opinion only the speed limit map would need to be altered.

10.2.12 Issues related to radio wave transmission

When asked to comment for this project, the Ministry of Transport raised the issue of possible interference from outside sources with any ISA system that is set up using radio spectra to transmit information. This

[59] www.ataassociates.com/Data.htm Accessed 14 May 2012.

issue will need to be dealt with during the development of any ISA system that might use these frequencies, such as for a transponder- or beacon-based system.

The Ministry of Economic Development (MED) confirmed that if an ISA system has a transmitting function (transmits radio waves), it must be covered by a licence. According to the MED there are two types of licence:

- *The individual licence* covers protected services such as cellular, AM/FM broadcasting and television broadcasting. Typically a licence per transmitter is required and regulatory fees apply.
- *General user licensing* covers some radio transmitters and uses such as consumer devices (eg Wi-Fi, cordless telephones). If a transmitter is covered (within the terms and conditions) by a 'General user' licence, then individual licensing is not required. General user licences have no protection from interference nor can they cause interference to other licensed services.

All equipment needs to meet an appropriate standard prescribed in the Radio Standards notice www.rsm.govt.nz/cms/policy-and-planning/spectrum-policy-overview/legislation/gazette-notices/product-compliance/radiocommunications-radio-standards-notice-2010.

New Zealand's radio frequency spectrum has been allocated and planned for certain uses; for example, there are particular bands for radio broadcasting, television broadcasting and cellular phones. This planning and separation of services is vital to ensure economic, efficient and interference-free use of the spectrum. New allocations and uses often require investigation, followed by a consultation process. Consultation processes can take a couple of years to conclude and if there are existing users in the band they may need to be moved, which can take five years or more.

With regard to intelligent transport systems, the MED has been looking at the 5.9GHz band. Details of this project can be found at www.rsm.govt.nz/cms/policy-and-planning/projects/intelligent-transport-systems-in-the-5.9-ghz-band. The project is aimed at Dedicated Short-Range Communications (DSRC), an emerging wireless ITS technology developed to transmit safety and traffic information over short distances. DSRC enables data communications between vehicles. It can also be used for communications between vehicles and roadside infrastructure to support traffic coordination and broadcast of safety information. Some of the features provided by DSRC include:

- intersection collision avoidance
- road condition warnings
- traffic emergency notifications.

It could conceivably also be used for ISA if roadside beacons were part of the rollout.

The Ministry has drafted a discussion paper on the allocation of spectrum for DSRC and would like to base its standard on a still-to-be-finalised joint US/European standard. The Ministry therefore plans to release the discussion document for consultation once there is more clarity about overseas ITS standards. This work indicates that if ISA was to use radio spectra, a reasonably complex approval process would be required to bed in the system, which would take time and money.

10.2.13 Other ITS technologies

While not necessarily a barrier, the expected proliferation of other ITS technologies in the (near) future should be taken into account when considering the deployment of an ISA system, particularly with regard to capitalising on any synergies and integrating technologies and/or systems where appropriate. Further consideration is required to determine the time frames for the likely large-scale penetration of different ITS technologies.

10.3 Conclusion

In principle, advisory ISA is likely to encounter few potential institutional, regulatory or other barriers outside those addressed elsewhere in this project, and neither the government (central or regional) nor the main players in the vehicle industry have concerns that cannot be easily answered. The main issues of general interest are of a practical implementation nature relating to:

- the possibility of speed information relayed to the driver differing from the speeds measured by enforcement devices, leading to complications for enforcement if ISA devices convey speeds slower than those measured by enforcement devices
- concern by motor industry groups that they receive the opportunity to make timely input in the event of any future government proposals for changes to requirements regarding the fitting of technology to vehicles – used-vehicle importers in particular would be interested in any move to compulsion that might involve having to fit after-market equipment to used imports
- concern over the confidentiality of information
- 'big brother'/government control ('nanny state') concerns.

However, there are a large number of technical issues related to mapping, speed measurement, speed limit databases, radio frequencies and confidentiality that may involve expensive policy work and legislative change. These may act as a barrier in terms of government expenditure constraints and finding timely legislative 'slots'. There are also unknowns regarding the number of existing ISA devices that would comply with any proposed legislative changes, or any willingness by vehicle manufacturers to comply with these proposed legislative changes.

Cost may also be a barrier in terms of promotion, as considerable promotion may be required – according to focus groups associated with this project, the 25–64 year age group appears to have some resistance to ISA.

A positive is that if the use of a suitably accurate ISA becomes ubiquitous, significant injury crash savings are expected. Other benefits could include considerable savings in the signposting of speed limits.

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Appendix A: Speed limit management

A.1 Land Transport Rule: Setting of speed limits

This appendix section outlines the main requirements of the Rule and subsequent amendments based on the September 2009 consolidation of the Rule.

Under the Rule, Road Controlling Authorities (RCAs) set enforceable speed limits on roads within their jurisdictions. The purpose of the procedures associated with the Rule is to ensure that the risk to public safety is minimised, and that the freedom of road users to travel at speeds that are reasonable and appropriate is protected. Checks and balances on the actions of RCAs are achieved through the Director of Land Transport Safety setting standards, auditing and monitoring the application of the Rule. RCAs are required to apply consistent methods to translate the national speed limits policy into a safe and appropriate speed limit for any given road, as set out in the procedures for setting speed limits, Speed Limits New Zealand (NZTA 2003).

The objective of the Rule is to contribute to a safe and efficient road network by establishing speed limits of 50km/h in urban traffic areas and 100km/h on rural roads and motorways; and authorising RCAs to designate urban traffic areas, to set speed limits other than 50km/h on urban roads and less than 100km/h on rural roads, and to set temporary speed limits associated with work on or near the road and for special events.

A speed limit is approved or changed by the NZTA when the speed limit is declared by notice in the Gazette.

Before setting a speed limit or designating or changing an urban traffic area, the Rule says an RCA must consult with persons that may be affected by the proposed speed limit, and give them reasonable time to make submissions on the proposal. These are listed below:

(a) Road controlling authorities that are responsible for roads that join, or are near, the road on which the speed limit is to be set or changed; and

(b) a territorial authority that is affected by the existing or proposed speed limit; and

(c) any local community that the road controlling authority considers to be affected by the proposed speed limit; and

(d) the Commissioner [of Police]*; and*

(e) the Chief Executive Officer of the New Zealand Automobile Association Incorporated; and

(f) the Chief Executive Officer of the Road Transport Forum New Zealand; and

(g) any other organisation or road user group that the road controlling authority considers to be affected by the proposed speed limit; and

(h) the [Agency.][60]

An RCA must establish and maintain a register of speed limits that records all speed limits, except temporary speed limits, for the roads under its jurisdiction. This register must be available for inspection by members of the public, at reasonable times, on request.

[60] Ie the NZTA.

Information recorded in the register of speed limits must include:

- *a full description of the roads or area to which the speed limit applies, including references to details of maps or other documents as appropriate; and*
- *the speed limit; and*
- *for a variable speed limit, the conditions under which the speed limit changes; and*
- *the date on which the speed limit came into force; and*
- *a record of the decision-making procedures of the road controlling authority carried out in accordance with 7.2(1); and*
- *for an urban traffic area in 10.1(1) or a saved speed limit in 10.1(2) that has been designated or validated in accordance with 10.1(3) a reference to the previous enactment under which the speed limit was set.*

Details of a speed limit that has been superseded by a new speed limit under the Rule must be retained on the register of speed limits for at least seven years from the date on which the new speed limit came into force.

Before a speed limit comes into force on a road, an RCA must ensure that all traffic control devices installed on the road are safe, effective and appropriate for the speed limit and comply with requirements for traffic control devices in Land Transport Rule: Traffic Control Devices 2004.

An RCA must install:

- a speed limit sign on the left-hand side of the road at or near, and no more than 20m from, the point on the road where a speed limit changes
- an additional speed limit sign on the right-hand side of the road, or on the central median where appropriate, if the estimated two-way annual average daily traffic at that point exceeds 500 vehicles
- additional speed limit repeater signs within each speed-limited length of road as defined in the Rule and shown in table A.1 below.

Table A.1 Maximum length of road between repeater signs for permanent and holiday speed limits

Speed limit (km/h)	Maximum length of road between signs (km)
60	2
70	2.4
80	2.6
90	3.0

Under the Rule, RCAs have an obligation to review speed limits when:

a) there is a significant change in the nature, scale or intensity of land use adjacent to a road

b) there is a significant change in a road, its environment or its use

c) the RCA receives a written request to do so from the NZTA.

The RCA also has the discretion to review speed limits if it decides to do so, or if it receives a written request from a person, organisation or road user group affected by that speed limit.

A.2 RCA interview summary

Table A.2 Summary of feedback from RCAs

RCA	Register and availability	Audit and review	Future plans	Reaction to nationwide system
Upper Hutt City Council	UHCC maintain a roads GIS layer. Bylaw with GIS map and schedule of roads is available on the web. The map in the bylaw shows speed limit zones; ie bounded areas, with labels describing the change points eg '75m from Plateau Road'.	Report goes to Council and they approve it, and changes are then incorporated into the bylaw. Only do the reviews required by legislation.	No changes planned (already have GIS).	Waste of time, would rather see money spent elsewhere. However, has no specific issue with it, particularly as they are already required to notify the NZTA of changes, so that would be as per normal. Thinks RAMM would be the logical place for such a system.
Hutt City Council	GIS layer + table/schedule of roads. Bylaw available on internet, which includes schedule and map.	Review speed limits as need arises (*ad hoc*). Changes are consulted on, approved by the NZTA, and approved by Council.	No changes planned (already have GIS). More speed limit changes will become more common; eg putting school zones in soon.	Should be easy to transfer as they already have GIS. Would prefer it to be in GIS as that is designed for everyone to look at (even if the info is fed from RAMM to GIS). Already required to notify the NZTA of changes, so that would be as per normal. Recording of temporary speed limits needs consideration/may be an issue. Sign location in relation to gazetted location is a problem. Asked why you would want a nationwide system, but agreed that it may be a good idea when explanation was given.
Auckland Transport	Currently a work in progress following amalgamation. Of the 7 previous Councils: · Auckland City Council have bylaw with maps, not published on the web, with 50km/h default in urban areas and exceptions mapped. · Franklin District Council, Papakura District Council, and Rodney District Council have bylaw maps available on		Working to consolidate the existing speed limits under the bylaws of the 7 former TLAs into one Auckland Transport Speed Limits Bylaw to have a complete written schedule of all speed limits. However, historic information will not be retained as 'this information is for the most part unavailable due to loss of institutional	Auckland Transport understands the benefit of establishing a national speed limit register, but question whether the benefit is sufficient to justify the cost of the work involved. Based on their experience in converting 7 existing TLAs' speed limits onto one common system, they believe the cost of doing this nationwide would be substantial.

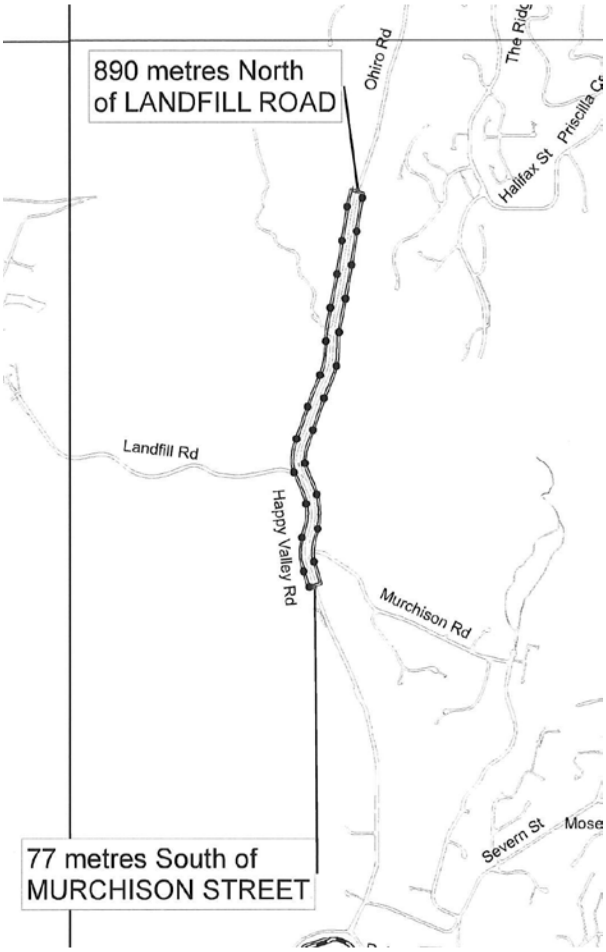
RCA	Register and availability	Audit and review	Future plans	Reaction to nationwide system
	the web, with 100km/h default and exceptions mapped. · Manakau City Council and North Shore City Council have bylaw with schedule and maps, available on web in Agenda Reports (ie meeting minutes). Default urban speed limit of 50km/h with exceptions mapped. Poor quality maps dependant on lists for clarity. · Waitakere City has bylaw on web with schedule but no map. Default 50km/h urban speed limit with exceptions listed.		knowledge and historical records in the transition process'. New bylaw will be either published on the web or available on request. Primarily a schedule of roads, with limited use of maps to define urban extents, which are used to determine default speed limits on new roads.	
Dunedin City Council	Bylaw with schedule + map on web. Map is a scalable GIS map without annotated distances. For consultation, and because people do ask for maps from time to time, they also produce nicer maps the community can understand. Have good GIS people, but suspect that not all Councils can afford this capability.	3-yearly review of areas requested or noticed by Council or review as requested. Consult community, notify the NZTA of changes and send maps to the NZTA. Currently reviewing Middlemarch and soon Otago Peninsula.	Previously used development-based process for setting speed limits and philosophy of focusing on main roads, but now using safety approach (safety clause in Setting of Speed Limits) and providing rationale for area wide view and community use. If they follow the default development rating process of the Setting of Speed Limits Rule they would not be decreasing the speed limits. Plans to expand use of safety approach to do area-wide reductions in speed limits so they are consistent; ie no more main road 80km/h and side roads 100km/h.	Would be good to have all speed limits on one map; ie particularly to have SH speed limits. Would be good if setting of speed limits process was a more holistic approach; ie like the High Risk Rural Roads Guide and more consistent with Safer Journeys. DCC have developed a rationale based on this approach.
Grey District Council	Bylaw with schedule of roads + GIS map of zones. Not available on the internet.	Reviewed every 5 years + on an as-needed/as-requested basis. Don't do an audit as such of signs, just keep tabs on it.	No plans to change anything.	No real comment/thoughts except for the comment 'it could be good'.

RCA	Register and availability	Audit and review	Future plans	Reaction to nationwide system
Tasman District Council	Bylaw with map and schedule on web. Map is probably GIS but not 100% sure (created by Steve Forbes MWH).	Instruct consultant to put in sign. Have never checked/audited signs in relation to gazette once in. The NZTA audit years ago resulted in an audit tracking sheet that they use (not sure what for exactly).	Expect more changes in future – want to put more 80km/h speed limits in rural areas and would like more 40km/h speed limits in urban areas.	Asked why you would want a nationwide system, but agreed that it may be a good idea when explanation was given. Stated that they are already required to notify the NZTA of changes, so sounds like business as usual. No preference over RAMM or GIS but don't seem to know much about it.

A.3 Uncertainty in speed limit location

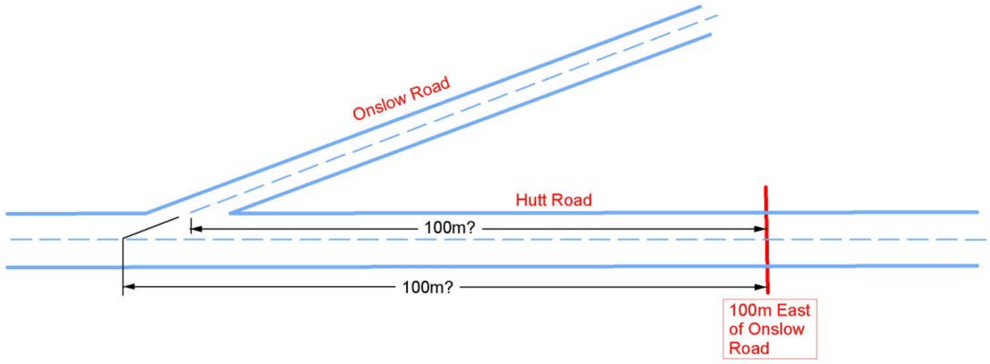
The first example relates to straight line distance versus running distance, as illustrated below in figure A.1. It shows the speed zone referenced as 890m north of Landfill Road, but it is unclear whether this is a running distance from Landfill Road or a straight line distance. The difference between the two equates to approximately 6m. Additionally it is not clear where on Landfill Road the measurement is taken from – the left kerb, right kerb, or centreline.

Figure A.1 Uncertainty due to lack of distance measurement definition (example from Wellington City Council speed zone description)



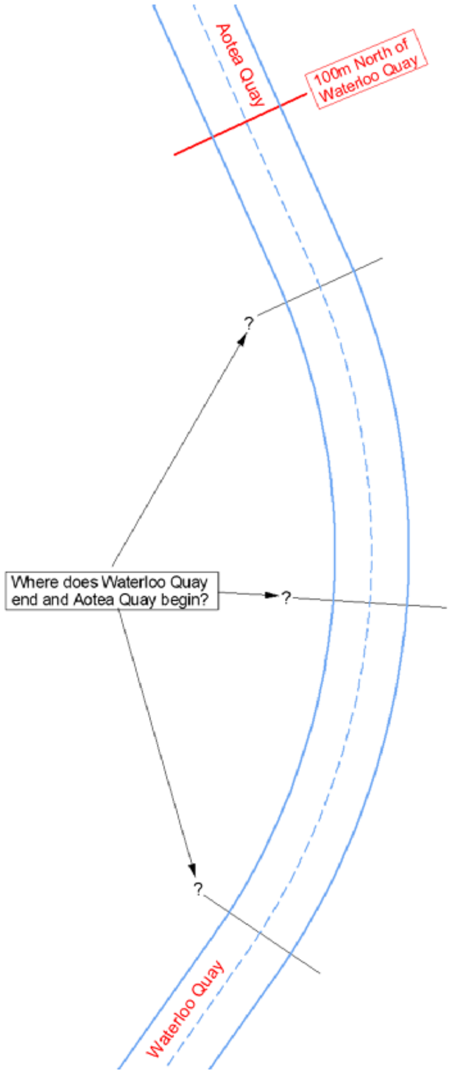
The second example is shown in figure A.2, which illustrates the lack of clarity regarding distance measurement, particularly at acute angle intersections. It is unclear where the measurement on Hutt Road is taken from the centreline, the north kerb, the south kerb, or the intersection of the two centrelines. It is interesting to note that other Traffic Control Device rules are formed in terms of the promulgation of kerb lines.

Figure A.2 Uncertainty due to measurement definition at acute intersection (example from Wellington City Council)



The third example, shown in figure A.3, relates to uncertainty surrounding ambiguous road boundaries.

Figure A.3 Uncertainty due to ambiguous road boundary (example from Wellington City Council



A.4 NZ Transport Agency speed limit system workshop minutes

Figure A.4 NZ Transport Agency (NZTA) speed limit system workshop minutes

MWH

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Meeting Minutes

Meeting Name	ISA Speed Limit Map Meeting		
Meeting Venue	NZTA		
Date Of Meeting	21 November 2011	Time Of Meeting	
Chairperson	Gina Waibl	Recorder	Gina Waibl

Project Details

Client Name	NZTA
Project Name	An Investigation in
Project Number	Z1962700

Attendees	**Organisation**
Fergus Tate	NZTA
Tim Hughes	NZTA
Richard Bean	NZTA
Philip Blagdon (part)	NZTA
Gina Waibl	MWH

Item	

1	**Other Speed Limit Maps / Management Systems**
	• Noted that there is an Australian ISA Working Group, which includes New Zealand and the Australian States.
	• Speed limit maps are being developed in the UK and in Australia. Speedlink is being developed in NSW. Users fill in a form and the information is fed through an e-system.
	• The issues facing Australia can be slightly different from the New Zealand situation, and include:
	  o Their speed limits vary by road type and driver's license class. In New Zealand, speed limits also vary by vehicle class and drivers license type. Solutions would be to have different map layers to cover each scenario or, more simply, to enable ISA users to select options in a user configurable ISA device. Whatever the solution, it should be flexible, as some users will regularly change status i.e. when towing a trailer.
	  o There is variability between States in Australia. Consideration needs to be given on how to make any speed limit map/database nationally unified.
	  o The speed limit sign is the legal speed limit, as opposed to the gazette notice as in NZ. This means that if an illegal sign is put up the Police will prosecute.
	
	Agreed that NZTA can probably create a speed limit mapping separate from Australia's.

2	**Aims and Benefits of a Speed Limit Management System** • One of the objectives of developing a national speed limit map should be to aid RCAs, and to make the management of speed limits more straightforward • Benefits include the enabling of national analysis for consistency of speed limits.
3	**Data Sources** • Each RCA is required to maintain a speed limit register • A number of commercial companies have created their own speed limit maps. These are understood to have been created by driving the network, and may therefore be of insufficient accuracy and may be out of date for the NZTA's purposes.
4	**Considerations** • Any speed limit map needs to be flexible enough to accommodate new technologies .i.e. there is now an iphone application for speed limits. • Differing speed limits by direction need to be able to be accommodated. • School zones and other variable speed limits need to be taken into account, for example,

P:\Z19500up\Z19627 - Advisory ISA System Investigation\Z1962700 - Advisory ISA System Investigation\03 - Correspondence - Minutes\Z1962700 ISA Speed Limit Map Meeting Minutes 21 Nov 2011.docx Page 1 of 2

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	the default speed could be reported and a flag included indicating that it is a variable speed limit. • The road centreline would need to be sourced for all of New Zealand. One option could be to use an open street map that can be edited by the public, which would act as a trigger for updating any centrally maintained road centerline. • Enable RCAs to make changes by directly accessing the NZTA system, and for the speed limit map to be viewable publicly. This way RCAs could simply provide a link to the system on their websites. • The system should be easy for RCAs to use, and should automatically generate maps and schedules by polygon. By using polygons, the building of new roads is easily accommodated. Gazette notices should also be able to be easily attached. • Existing GIS data should be able to be loaded into the system, and specification/guidelines should be developed so that new data collected can be directly imported i.e. GPS co-ordinates recorded. • Ensure ease of use for RCAs and enable RCA's to manage the data themselves, as it would be more difficult if RCAs were required to notify the NZTA of changes, particularly if they still maintained their own duplicate systems. • Facility to provide feedback so that mistakes can be corrected. • Allow for elevated motorways and other instances where roads may be multi-layered or 3-dimensional. • How data will be moved between the "speed limit map" and speed limit devices i.e. at present in-car navigation systems are often updated by the user purchasing an updated map. Other options include two way cellular communications i.e. via SIM card installed in the device.
5	**Ownership:** • The NZTA could buy speed limit data and then maintain it, or preferably, • The NZTA could purchase speed limit data as a service. The intention is that the NZTA would make speed limit data freely available.
6	**Rule Changes:** • Specify how speed limit data should be stored, including requirement to record GPS co-ordinates • Require GIS to be used • Take care not to increase the burden on RCAs Consider further Rule changes that may be beneficial.
7	**Other Notes:** • RCAs do not require approval from the NZTA to change speed limits. • A model bylaw has been developed for RCAs to use. • Optical recognition of signs may be an alternative means for in-vehicle devices to detect speed limit changes. • Speed limit map accuracy (and GPS coverage) is more of an issue for supportive and mandatory ISA systems. • In order to detect school zones and other temporary speed limit changes as they occur, it would make sense for transponders to be used. • Mandatory and supportive ISA systems can now easily be set up in a vehicle i.e. by plugging in to the vehicle sensors. • It is possible to have different speed limits in each direction, but the guidance on setting on speed limits recommends that this only be done where the carriageway is divided. Further ISA trials would need to be undertaken to ensure that the separation between carriageways is sufficient for ISA devices to accurately display the speed limit in the direction of travel. This may require more advanced ISA devices, such as those with inertial gyroscopes.

A.5 Appendix A references

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Appendix B: GNSS coverage in New Zealand

B.1 Introduction

This appendix expands on the study in the main body of the report of the coverage, reliability and accuracy of consumer grade Global Navigation Satellite System (GNSS) receivers in New Zealand.

B.2 Global Navigation Satellite Systems (GNSS)

B.2.1 Purpose

This section is a very basic overview of GNSS and the associated errors. The purpose is to inform the reader but not overwhelm with unnecessary information. For this reason, substantial information has been omitted.

B.2.2 Common terms explained

Table B.1 Common terms

Term	Description
GNSS	Global Navigation Satellite System – a generic term for satellite navigation.
GPS	Global Positioning System – a satellite navigation system owned and operated by the US government (also known as NAVSTAR (NAVigation System for Timing And Ranging).
GLONASS	GLObal NAvigation Satellite System – a satellite navigation system owned and operated by the Russian government.
Galileo	A satellite navigation system being built by the European Union and European Space Agency.
Compass	A satellite navigation system being built by the Chinese Government.
Survey-accurate GPS	A GPS receiver that typically delivers centimetre positional accuracy.
Mapping-grade GPS	A GPS receiver that typically delivers sub-metre accuracy suitable for GIS applications.
Consumer-grade GPS	Typically handheld with an accuracy >±3m. In the context of this report, also referred to as recreational-grade GPS.
SBAS	Space Based Augmentation System – a system that can increase the accuracy of GPS.
Elevation mask	A quality-control setting commonly used on mapping or survey-grade receivers whereby all satellite signals from below a certain altitude are omitted from position calculations. The rationale behind an elevation mask is that signals from a low altitude are more likely to be multipath or to have been affected by the atmosphere and obstructions such as trees. Some consumer-grade receivers have the ability to set the elevation mask.
In-car navigation	A generic term for a consumer-grade GPS receiver used primarily for vehicle navigation.

B.2.3 GNSS segments

GNSS has three segments:

- the space segment, which consists of satellite vehicles (commonly called SVs, or just satellites)
- the control segment, which is a series of ground-based stations that determine and control the position (or orbit) of the satellite vehicles

- the user segment, which is what we use; ie an antenna, a processor and a display – for civilian application these are usually combined into one unit, which is commonly called the receiver.

B.2.4 How position is calculated

Position is calculated as follows:

1 The satellite vehicles transmit a weak signal to earth.

2 The receiver's antenna picks up the signal and measures the time lag from when the signal was sent to when it arrives at the receiver (both the SV and receiver have clocks). From this time lag, the distance between the SV and receiver can be calculated.

3 Since the position of the SVs are known, the position of the receiver can be calculated – much the same way as you would with a compass and pencil, using intersecting circles. A minimum of three satellites is needed to calculate a two-dimensional position, and four satellites for a three-dimensional coordinate.

B.2.5 GNSS systems in place at present

The most commonly used system at present is GPS. Some higher-end receivers also use GLONASS to augment GPS. The European (Galileo) and Chinese (Compass) systems are yet to be fully operative (refer to table B.1).

B.2.6 Factors affecting GPS accuracy

There are many factors that affect the accuracy of consumer-grade receivers. These include (but are not limited to):

- satellite geometry (the 'spread' of the satellites throughout the sky within 'view' of a receiver)
- atmospherics (atmospheric conditions can 'degrade' satellite signals)
- obstructions (trees, buildings, etc)
- antennae
- number of receiver channels
- multipath
- satellite position
- time keeping.

B.2.6.1 Satellite geometry

As discussed in section B.2.4, position is derived from distance measurements between the satellite and receiver. Inherent to the distance measurement is a certain amount of error. In figures B.1 and B.2, the error is represented by the grey area surrounding the black line. The resultant positional error is shaded blue.

Figure B.1 Good satellite geometry

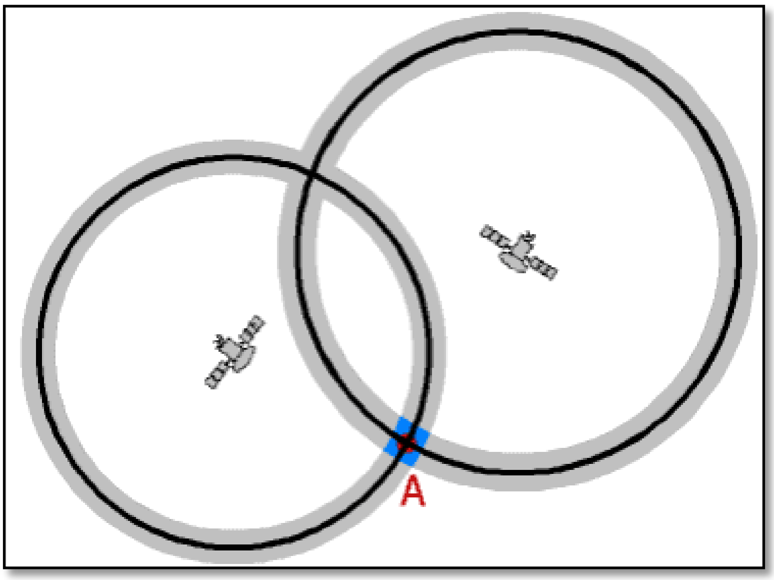
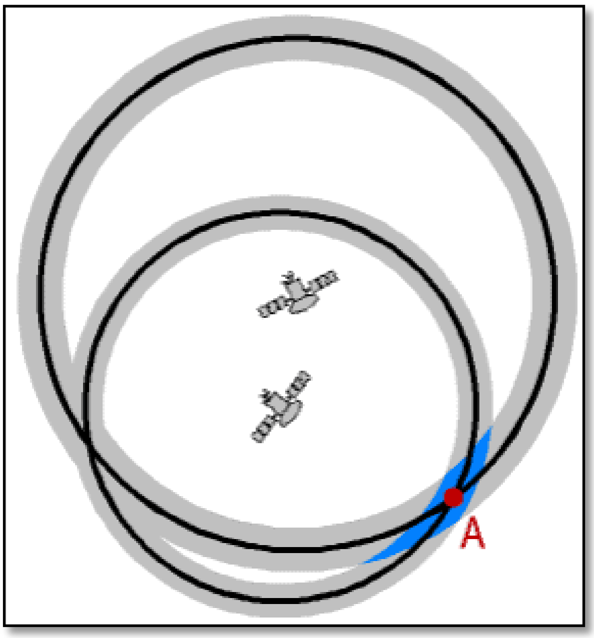


Figure B.2 Poor satellite geometry



As can be seen from the diagrams, a poor satellite geometry as shown in figure B.2 gives a greater overlap of the distance 'uncertainty'.

A common term used in conjunction with satellite geometry is DOP values (Dilution of Precision). There are different variants of DOP value; for example, Horizontal DOP (HDOP) and Positional DOP (PDOP). PDOP refers to a three-dimensional position and HDOP refers to a two-dimensional position. A low DOP indicates good satellite geometry and this in turn indicates a *higher probability* of good accuracy. A high DOP indicates weak satellite geometry with a *lower probability* of good accuracy. DOP in itself is not a quantitative measurement of error.

Another factor pertinent to New Zealand is that the number of GPS satellites and PDOP tends to reduce with latitude. The table below shows the difference of PDOP and number of GPS satellites between Dunedin, New Zealand and Namorick in the Marshall Islands. Dunedin sits at a latitude of 45˚ 55' South and Namorick at 5˚ 37' North. Both have a similar longitude. In addition to an elevation mask of 0˚, an elevation mask of 15˚ has also been applied to simulate loss of satellite signal through obstacles such as buildings and topography.

Table B.2 The effect of latitude on satellite availability

	Namorik, Marshall Islands 5˚ 37' North, 168˚ 37' East	**Dunedin, New Zealand 45˚ 55' South, 170˚ 12' East**
Average number of satellites with 0˚ elevation mask	13	12
Average number of satellites with 15˚ elevation mask	9	8
Average PDOP with 0˚ elevation mask	1.4	1.4
Average PDOP with 15˚ elevation mask	2.2	2.2
Total minutes with 3 satellites or less with 0˚ elevation mask over a 24hr period	0	0
Total minutes with 3 satellites or less with 15˚ elevation mask over a 24hr period	0	0

As can be seen in the table, the difference in number of satellites and PDOP is quantifiable but not significant.

As discussed in section B.2.6, a two-dimensional position can be calculated from three satellites. To achieve this, the height of the receiver must be assumed. If the height is significantly different from the assumed value, errors in the two-dimensional position can occur.

Concerning satellite geometry, the optimum scenario is to have an even spread of satellites in the sky. However, this is usually not possible due to a number of factors such as latitude, and terrestrial obstructions such as buildings and hills.

B.2.6.2 Atmospherics

The GNSS satellite signal has to pass through two distinct hemispheres before reaching earth. The upper hemisphere is called the ionosphere and the lower hemisphere called the troposphere. The effect of the hemispheres is to vary the velocity of the signal, which in turn affects the accuracy of the distance measurement discussed in section B.2.4 above. The effects of the ionosphere and troposphere can be partially offset by calculation and modelling.

B.2.6.3 Obstructions

As noted in section B.2.4, the signal broadcast from the satellite vehicles is very weak. In fact the signal is incapable of passing through solid objects and can be degraded or weakened when passing through vegetation.

B.2.6.4 Antennae

In general, modern antennae are more sensitive than previously, allowing a greater number of satellite signals to be received in challenging environments. Some antennae are also more resistant to multipath (see below).

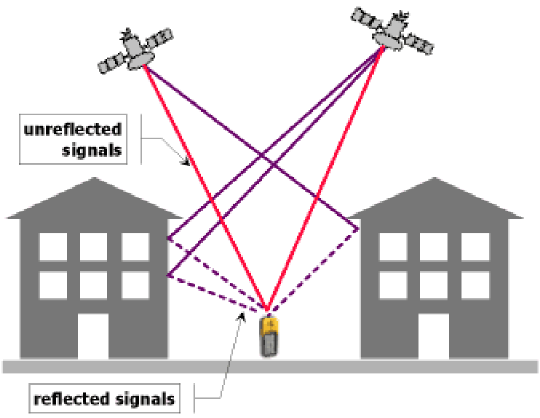
B.2.6.5 Number of receiver channels

The number of receiver channels relates to the number of satellites a receiver can 'read' at any one time. The more channels or satellites a receiver can read, the higher the probability of greater positional accuracy.

B.2.6.6 Multipath

Multipath occurs when the antenna receives a satellite signal that has 'bounced' off a nearby surface.

Figure B.3 Multipath signals



B.2.6.7 Satellite position

The position of the satellite is dynamic and influenced by many variables such as gravity and solar force. Errors in the position of the satellite in turn affect the accuracy of the calculated coordinates of the receiver.

B.2.6.8 Time keeping

Inaccuracies and deviation in the satellite clock can cause inaccuracies in the calculated coordinates of the receiver.

B.2.6.9 Jamming

Jamming is a case where the satellite signal is 'drowned' out by another signal. Due to the weak nature of the satellite signal, this is relatively easy to do. Jamming can be categorised as deliberate (man-made), natural, or accidental (man-made).

- *Deliberate jamming*: *New Scientist Magazine* (Hambling 2011) reports that not only can GPS jammers be purchased over the internet, but they can be used to block permanent GPS tracking on trucks and some road toll systems that use GPS.
- *Solar jamming*: Solar flares have been proven to disrupt or jam GPS signals. A 15-minute flare in 2005 caused a 50% drop in GPS signal (Oberst 2006). The sun generally runs through an 11-year cycle, with the last peak of solar activity occurring in 2011 and 2012. Flares at peak activity can be up to 10 times as intense as the 2005 event and last considerably longer (ibid).
- *Man-made jamming*: A recent plan to erect 40,000 4G wireless network stations in the US has been met by opposition from GPS users and manufacturers. Tests carried out by GPS receiver manufacturer Garmin® have found that total jamming could occur as far as 1km from any such station for the nüvi® 265W in-car navigation unit (Burgett and Bronson 2011).

B.2.6.10 Manufacturer's accuracy specifications

Manufacturer's accuracy specifications are as follows:

- The Garmin® website specifies an accuracy of 'within 15m on average' and with WAAS, 3m (see section B.3.4 for a description of WAAS)
- The manual for the TomTom® wireless GPS receiver (Palmtop B.V., 2003) states an accuracy of 10m (2d RMS).

B.3 Tests on consumer-grade GPS accuracy

Three tests of consumer-grade GPS accuracy are summarised below. Please note that all tests used a number of measurements on a single point to derive statistical analysis, ie an average. Most consumer-grade receivers do not have the ability to display averaged positions.

B.3.1 Journal of Forestry (US), 2005

This experiment was carried out on six consumer-grade receivers in a variety of different situations (Wing et al 2005). The average error (95% confidence level) ranged from 2.6 to 34.6m in open areas, 2.5 to 12.2m in young forest, and 5.5 to 21.6m in closed canopy.

B.3.2 Journal of Arkansas Academy of Science (US), 2009

This experiment was carried out in Arkansas (Weih et al 2009) on four recreational-grade GPS receivers in a variety of different situations. In open areas, the average error (95% confidence level) ranged from 3.5 to 6.7m in open areas, 7.7m to 65.6m beside buildings, and 20.1m to 25.2m under a tree canopy.

B.3.3 Otago University (NZ), 2010

An experiment by the Otago University School of Surveying (Denys 2010) on three handheld GPS receivers found that with 5 to 10 satellites, the accuracy was better than ±7m at the 95% confidence level. As the experiment was carried out in a location clear of major obstacles (such as trees and buildings), the result should be interpreted as an optimal, rather than a 'real-life', result. The study also found that the receivers on occasions demonstrated errors of 20m for no apparent reason.

B.3.4 Space-based augmentation system (SBAS)

The underlying theory of SBAS is that the accuracy of the user segment can be increased if the corrections for the ionosphere, satellite clock and satellite orbit errors are broadcast to the user segment. The architecture for SBAS is similar to that of GNSS in that it has: a *ground or control segment* that determines the errors and broadcasts these to the *space segment,* which in turn broadcasts the corrections to the *user segment*.

At present there a number of SBAS systems operating throughout the world, concentrated primarily on North America, Europe, Japan and India. The North American System is called WAAS (Wide Area Augmentation System) and as of 2009 had 25 ground monitoring stations and two geostationary satellites broadcasting the corrections. Some consumer-grade GPS receivers have the ability to incorporate SBAS corrections. However, in the context of this study, it is presumed that no SBAS corrections are available in New Zealand due to geographical isolation.

B.3.5 Summary

In summary:

- GPS is the industry standard for GNSS systems.
- There are a number of different grades of GPS systems available.
- The term 'recreational' or 'consumer' grade is the most attributable to in-car navigation.
- There are a number of different errors that can affect GPS.
- Studies indicate that the accuracy of consumer-grade GPS varies greatly, but generally positional accuracy is most degraded under tree cover and beside obstacles such as buildings.
- From studies carried out, an accuracy of ±15–20m in 'most' situations would appear to be a realistic if not conservative estimate of consumer-grade GPS.

B.4 Desktop study

B.4.1 Purpose

The purpose of the desktop study was to examine the effects of latitude and obstructions on satellite availability and DOP.

B.4.2 Software used

Trimble Office Planning Software was used in the desktop study.

B.4.3 Methodology

The methodology used was to:

- obtain the latest almanac (the almanac is an electronic file that lists the orbits of the SVs)
- import it into the planning software
- select a date and three locations in New Zealand
- produce tables for each site showing satellite availability, PDOP and HDOP over a 24-hour period at a 0˚ elevation
- mimic obstructions by repeating with a 15˚ elevation mask (screen out all satellites below 15˚), then with 30˚ and 45˚ masks
- repeat exercise using GLONASS satellites in addition to GPS satellites.

B.4.4 Results

The results are summarised in the tables on the next pages.

Table B.3 Satellite availability with 0˚ elevation mask

	Auckland GPS	Auckland GPS + GLONASS	Wellington GPS	Wellington GPS + GLONASS	Dunedin GPS	Dunedin GPS + GLONASS
Average number of satellites	12	20	12	20	12	21
Average PDOP	1.4	1.0	1.4	1.0	1.4	1.0
Average HDOP	0.8	0.6	0.8	0.6	0.8	0.6
Total minutes with 3 or less satellites over a 24hr period	0	0	0	0	0	0

Table B.4 Satellite availability with 15˚ elevation mask

	Auckland GPS	Auckland GPS + GLONASS	Wellington GPS	Wellington GPS + GLONASS	Dunedin GPS	Dunedin GPS + GLONASS
Average number of satellites	8	14	8	14	8	14
Average PDOP	2.3	1.7	2.3	1.6	2.2	1.6
Average HDOP	1.2	0.8	1.1	0.8	1.2	0.8
Total minutes with 3 or less satellites over a 24hr period	0	0	0	0	0	0

Table B.5 Satellite availability with 30˚ elevation mask

	Auckland GPS	Auckland GPS + GLONASS	Wellington GPS	Wellington GPS + GLONASS	Dunedin GPS	Dunedin GPS + GLONASS
Average number of satellites	5	9	5	9	5	9
Average PDOP	6.5	3.7	6.3	3.7	5.6	3.5
Average HDOP	2.6	1.4	2.6	1.5	2.6	1.4
Total minutes with 3 or less satellites over a 24hr period	60	0	90	0	90	0

Table B.6 Satellite availability with 45° elevation mask

	Auckland GPS	Auckland GPS + GLONASS	Wellington GPS	Wellington GPS + GLONASS	Dunedin GPS	Dunedin GPS + GLONASS
Average number of satellites	3	5	3	5	3	5
Average PDOP	21.0	30.2	19.5	23.0	17.3	19.7
Average HDOP	5.3	6.8	4.3	6.5	3.9	6.5
Total minutes with 3 or less satellites over a 24hr period	1095	75	1125	90	1230	90

The results show that the difference between GPS and GPS + GLONASS becomes more pronounced as the elevation mask increases, with similar results obtained for Auckland, Wellington and Dunedin.

B.4.5 What is a typical horizon?

To determine a typical horizon within a central city, a quick test was carried out whereby two sites were chosen and measured. As can be seen in following figures, a 10–15° horizon is more realistic than a 0° horizon.

Figure B.4 Example of a typical central-city horizon

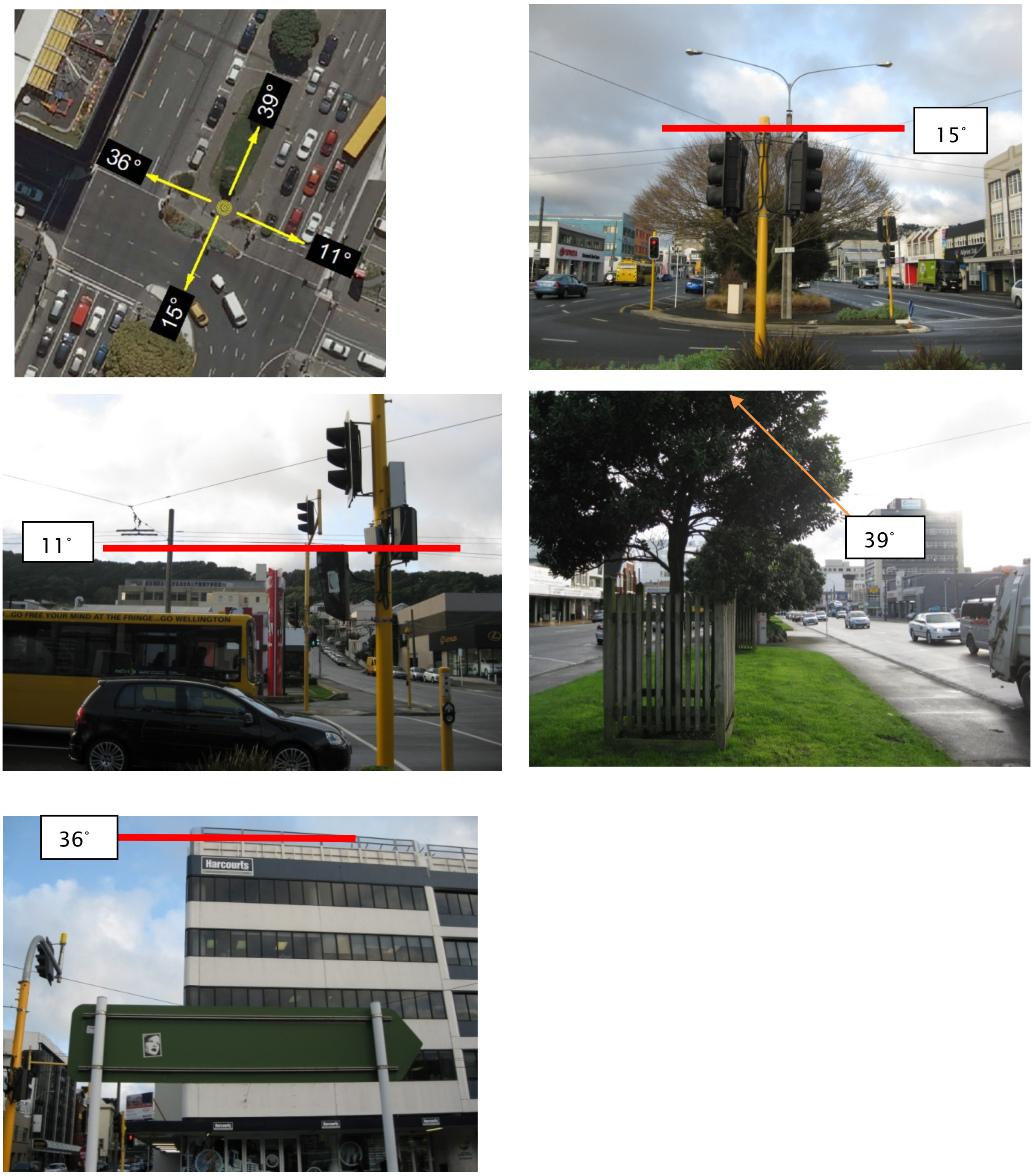


Figure B.5 Example of a typical central-city horizon

B.4.6 What is a good DOP value?

Generally, a DOP value under 7 is acceptable. Values over 7 represent a lower confidence level. A high DOP does not necessarily mean a lower accuracy – just an increased likelihood of low accuracy.

B.4.7 Summary

The test applied was simplistic. In real life it is unlikely that the surrounding horizon would be a constant 15° or a constant 45°. Furthermore, a 45° obstruction over one part of the sky could obstruct no satellites, but applied over a different part could obstruct many.

However, the test did show the following:

- There was little appreciable difference in the number of satellites over the cities tested.
- DOP did not necessarily decrease when more satellites were available.
- The effect of an elevation mask was significant. The amount of time with three satellites or more available decreased dramatically with a rising elevation mask.
- The availability of GLONASS satellites could improve DOP and the amount of time with three satellites or more available.

B.5 Field study

B.5.1 Purpose

The purpose of the field study was to compare the positional fixes of an average in-car GPS navigation unit against a higher accuracy.

B.5.2 Overview of methodology development

The original brief to the field study was to undertake a field trial (limited to one day) of a consumer-grade GPS (of industry standard) within Wellington and compare the positions captured to the true position whilst recording the number of satellites and PDOP.

The first decision to be made was on the field methodology for the consumer-grade GPS. Two options were identified:

- Record a series of static positions with a handheld GPS.
- Record a series of positions in a moving vehicle with a specific ‘in-car’ GPS navigation unit.

The first option was considered due to the ready availability within the Wellington MWH office of a handheld GPS with recording capabilities. However, the unit was several years old and relatively out of date compared with what is available today. As such it was decided that an ‘in-car’ GPS navigation unit with recording capabilities would be purchased (the second option), as this would provide a more realistic test.

The next step was to determine a methodology for the recording of the ‘true’ position with the associated metadata (PDOP and number of satellites). Two options were identified:

- Fix a survey-grade GPS receiver to the vehicle to provide the ‘true’ position and associated metadata.
- Provide the ‘true’ position via a geo-referenced ortho-rectified aerial photograph and an ‘estimate’ of the metadata via the Trimble pre-planning software.

The first option was discarded because of the following factors:

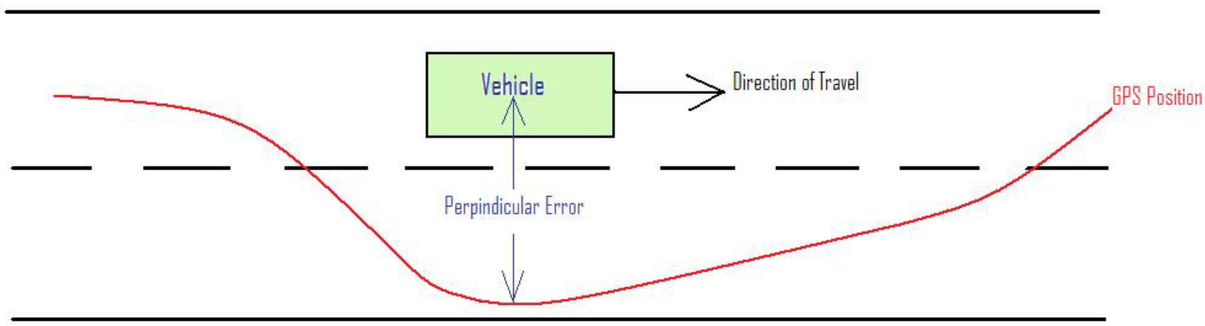
- The daily hire rate of Survey Grade GPS was prohibitive.
- Survey-grade GPS would not provide sufficiently accurate positions in challenging environments such as the proposed route through Wellington City.
- The aerial photograph would provide an easy visual appreciation of the test route.
- The accuracy of the aerial photograph would be sufficient for the purposes of this test.

B.5.3 Issues identified with methodology

At the methodology development stage as described in section B.4.3, an important issue was identified, namely: *How do you test the accuracy of the GPS in the direction of travel?*

While not directly identified in the scope, this is central to the purpose of the report. Figure B.6 shows the scenario of the GPS 'oscillating' around the car's direction of movement but generally going in the same direction as the car it is fixed to (as you would expect). While the position perpendicular to the direction is not of critical value to judging the moment the car passes from a 100km/h speed zone to a 50km/h speed zone, the position in the direction of travel is.

Figure B.6 GPS position versus direction of travel



The obvious way to test this directional accuracy is to record a position on the GPS as you pass a feature with a known position. However, there are a number of problems with this approach:

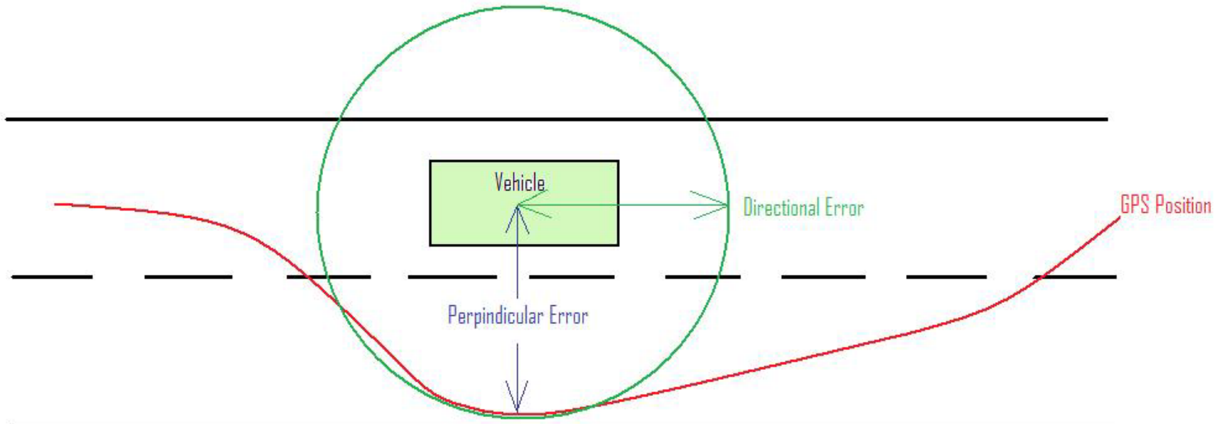
- Depending on the vehicle's travelling speed, there could be a considerable error introduced by when the user presses the button to record the position; ie a half-second delay at 30km/h equates to 4.2m, 7m at 50km/h, etc (see table B.7).
- Assuming position calculation time within the GPS is instantaneous, the refresh rate of the GPS receiver could also play a significant part. For example, if the receiver updates every second, there could be errors in a similar magnitude to those described above.
- Again assuming an instantaneous calculation time, there will also be an inherent time lapse to when the data is displayed on the screen (a typical LCD computer screen has a refresh rate of 60Hz or 0.017 seconds).

Table B.7 Distance (in metres) travelled at different speeds

Time (sec)	Distance travelled at 30km/h	Distance travelled at 50km/h	Distance travelled at 70km/h	Distance travelled at 100km/h
0.02 seconds	0.2	0.3	0.4	0.6
0.5 seconds	4.2	6.9	9.7	13.9
1 second	8.3	13.9	19.4	27.8
2 seconds	16.7	27.8	38.9	55.6
5 seconds	41.7	69.4	97.2	138.9

Due to the inaccuracies described above, the accuracy in the direction of travel was not tested. However, as the methodology development described in section B.4.3 effectively tests the accuracy of the GPS perpendicular to the direction of travel *and* if the assumption is made that the error of the GPS is circular, it in turn can be assumed that the error perpendicular to the direction of travel is the same as to the direction of travel.

Figure B.7 Circular error assumed



B.5.4 Methodology

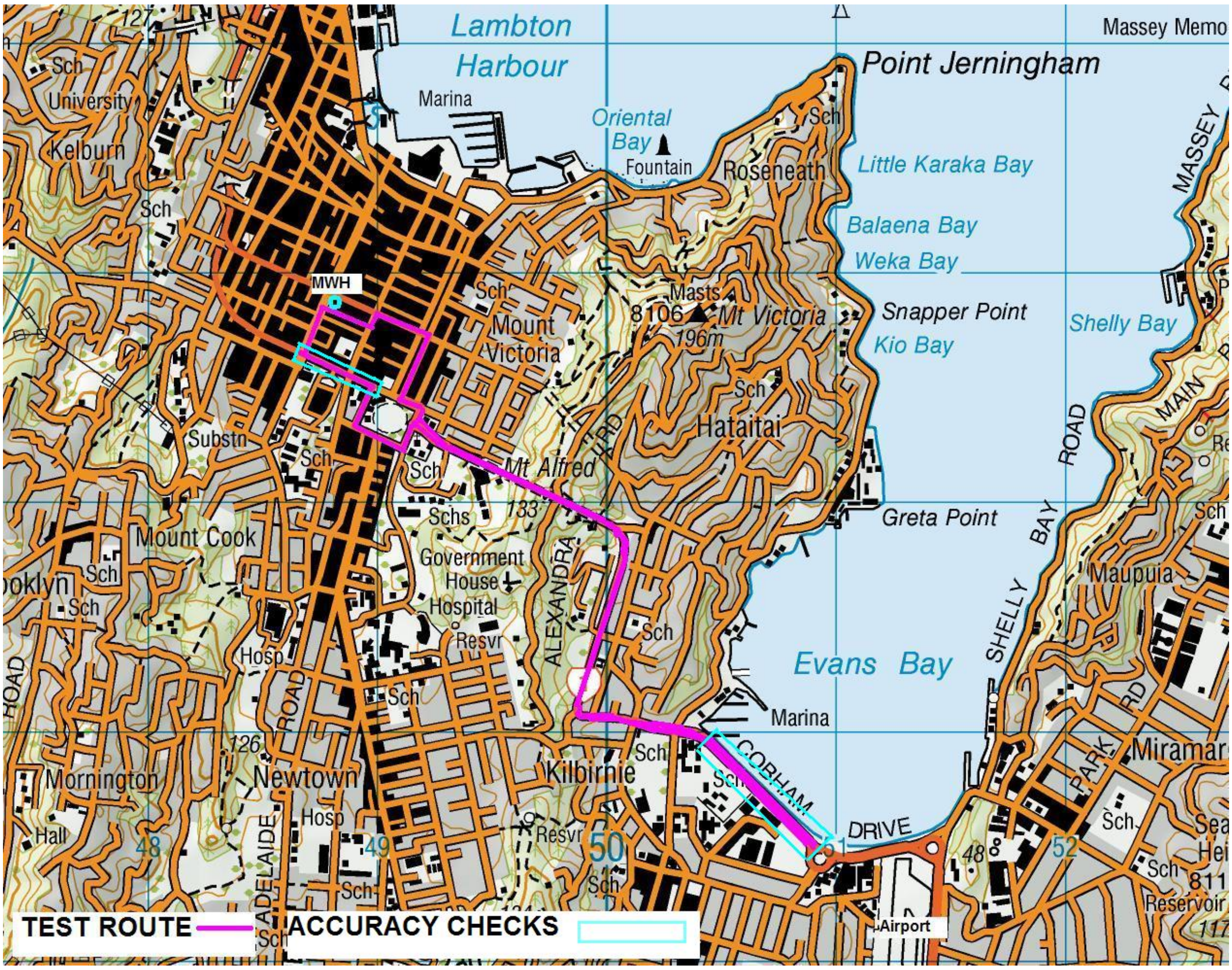
An ‘average’ in-car GPS was acquired – specifically, a Garmin® nüvi® 265. The unit was chosen because of its price ($120 ex-floor model – normally about $250) and its ability to log GPS positions at one-second intervals. The unit was installed on the front window screen of a Mazda Bounty and the data logger was activated.

A fixed course was then followed from the MWH car park (near the junction of Taranaki Street and Vivian Street in Wellington) to Cobham Drive via the Mount Victoria Tunnel and back again. This route provided a good mixture of ‘urban canyons’, tree cover, open areas and areas with zero GPS availability (the Mt Victoria Tunnel). Care was taken to follow specific lanes for later comparisons.

After each run, the information was downloaded and converted from geographical coordinates (WGS-84) to the New Zealand Transverse Mercator Coordinates through the Land Information New Zealand on-line coordinate converter. The route of the course was then overlaid onto Geo-referenced Wellington City Council (WCC) Aerial Imagery to provide an easy visual reference of the GPS accuracy.

The WCC Council Imagery has an estimated horizontal accuracy of ±0.3m. To test the robustness of the imagery accuracy, features with known coordinates were overlaid on the imagery and compared at either end of the route. All eight features tested were within 0.3m of the stated position (see figure B.8).

Figure B.8 Test route



Two runs were made to test repeatability – the first at 9:30am and the second at 2pm. The graphs following show the number of satellites and DOP values with a 10° elevation mask. Please note that the horizontal axis of the graphs is the local time in 24hr format. The colours shown on figure B.9 relate to the number of satellites; ie dark green indicates 7 satellites, light green 8 satellites, etc.

Figure B.9 Number of satellites for test times

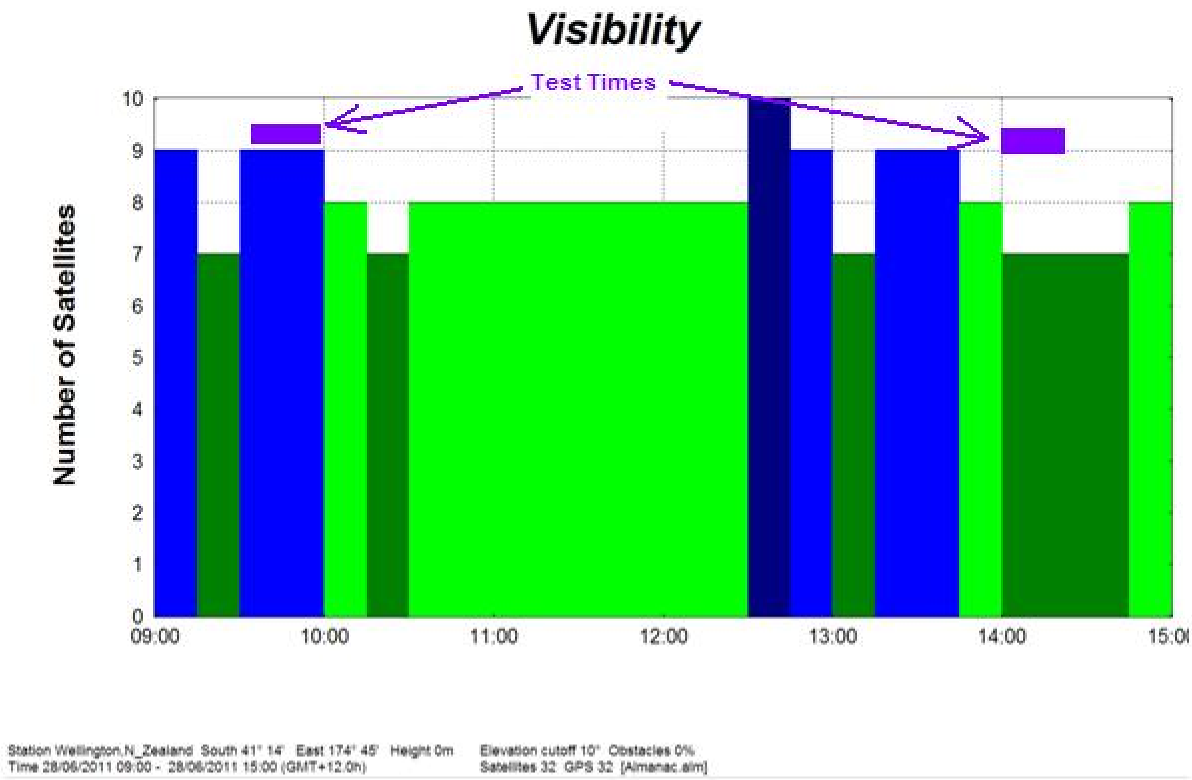
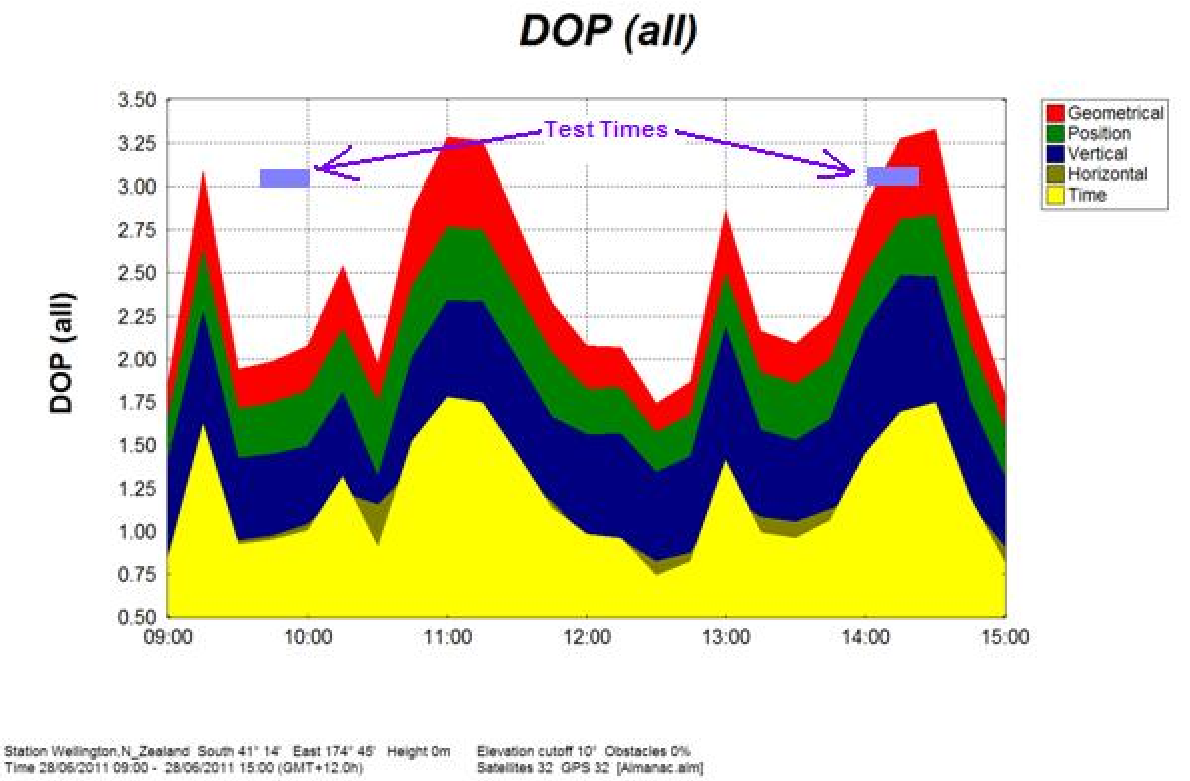


Figure B.10 DOP for test times



After downloading, the GPS positions were then compared to the centreline of the lane followed (by tracing of the aerial image) and a statistical analysis was carried out.

B.5.5 Problems encountered

After the test was carried out, an interesting anomaly was identified. Where there should have been no GPS signal and thus no positions in the Mount Victoria Tunnel, there was in fact approximately 33 seconds of positions within the tunnel on each of the four times the tunnel was entered.

Research of various internet forums indicates that the Garmin® nüvi® alters the 'raw' GPS positions in a number of ways to best reflect the true position (unfortunately, no material could be found published by Garmin® relating to this).

It could be that the Garmin® nüvi® 'pulls' the GPS position to the nearest mapped road (the mapped road being held in the GPS receiver) and/or a form of 'dead' reckoning is applied whereby the last fixes of position (and thus direction and velocity) are used to extrapolate the vehicle's position in a poor-GPS environment.

A separate test was then set up whereby two different types of logging were carried out at the same time – one being recorded to a file called 'current.gpx' and the other to a file called 'gps.bin'. Research from various GPS forums indicate that the 'current.gpx' file is a reflection of where the GPS position is 'pulled' to the nearest road in the Garmin® database. The 'Bin.log' is more representative of the true position (once again, no material could be found published by Garmin® relating to these topics) and records a position every second. Both results were downloaded and mapped onto a WCC aerial photograph. As can be seen, the red route from the 'Current.GPX' appears to have been 'pulled' to an arbitrary road centreline (evidenced by the straight lines and right-angle turns), whereas the 'Bin.log' file appears to be more realistic; ie quite accurate in open areas but less so near large buildings. The regularity of the positional fixes is also apparent from figure B.11 (a positional fix being represented by a solid circle).

Figure B.11 Comparison of GPS files

The data was then examined from around the Mount Victoria Tunnel Portal.

Figure B.12 Comparison of GPS files around western portal of Mt Victoria Tunnel

Figure B.13 Comparison of GPS files around eastern portal of Mt Victoria Tunnel

As can be seen from figures B.12 and B.13, the positions from the Bin file suggest that the course of the vehicle was extrapolated for approximately 4–5 seconds while in the tunnel and then 'pulled' to the 'mapped' road. As such, the positions of the Bin file were used for the process of the statistical analysis, as they represented the best form of 'raw' data.

Another interesting note associated with the Bin file was that when the vehicle was stationary, the unit would continue to record but the coordinates would 'stay' the same. Previous experience with survey-grade GNSS receivers has shown that coordinates constantly change from second to second.

B.5.6 Recording accuracy

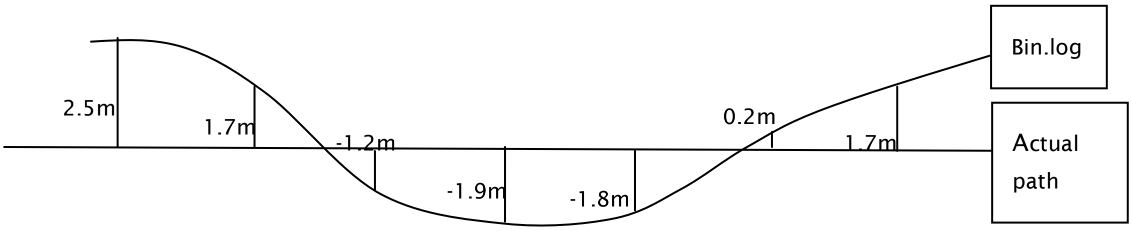
The Garmin® nüvi®265 records coordinates in latitude and longitude in decimal degrees to six decimal places. This equates to an accuracy of approximately 0.1m for a 0.000001 change in latitude or longitude.

B.5.7 Statistical analysis of results

The GPS positions from the afternoon and morning sessions (from the Bin files) were loaded into a survey-specific software called 12d and compared to the 'traced' position of the actual course taken by way of perpendicular offsets every 10m. Figure B.15 shows a conceptual diagram of the report generated by 12d.

Figure B.14 Actual path versus GPS positions around Mt Victoria Tunnel

Figure B.15 Conceptual diagram of 12d report



The report was then imported to an Excel spreadsheet and the following simple statistics were determined:

- the average magnitude offset; ie assuming all the offsets were positive
- the same as above but omitting any positions within the Mt Victoria tunnel
- the maximum offset
- the standard deviation of the offsets (using positive and negative offsets)
- the same as above but omitting the positions within the Mt Victoria tunnel.

B.5.8 Results

The results of the field study are summarised in table B.8.

Table B.8 Results

	Average magnitude of offset between actual path & GPS positions (m)	Average magnitude of offset between actual path & GPS positions excluding Mt Victoria Tunnel (m)	Maximum offset (m)	Standard deviation of offset between actual path and GPS positions (m)	Standard deviation of offset between actual path and GPS positions excluding Mt Victoria Tunnel (m)
Morning session	1.6	1.5	9.4	2.0	1.9
Afternoon session	1.4	1.3	11.5	2.1	1.9

B.5.9 Summary

In summary, the field study showed the following:

- The in-car navigation unit tested appeared to ‘filter’ the results of the GPS positions in certain circumstances.
- The error measured was perpendicular to the direction of travel of the vehicle, as it was not possible to accurately measure directional error with the equipment available.
- The maximum offsets observed were near the Mt Victoria Tunnel portals and tall buildings.
- The ‘true’ position was derived from an aerial photograph with accuracy of +/- 0.3m. In turn, the path of the vehicle was traced onto the aerial photograph as the centre of the lane. The combined accuracy was estimated as 0.6m at one standard deviation.
- Taking into account the accuracy of the GPS and accuracy of ‘true’ position, the combined accuracy at one standard deviation was in the order of 2.6m. Converting to a 95% confidence level gave 5.1m; ie 95% of the time the GPS was correct to within 5.1m.
- There was not enough testing to build up enough data for a more rigorous statistical analysis.

B.6 GPS coverage in New Zealand

Figure B.16 GPS coverage for the NZTA's HSDC surveys, plotting 10m data points, 2009–10 (left) and 2010–11 (right)

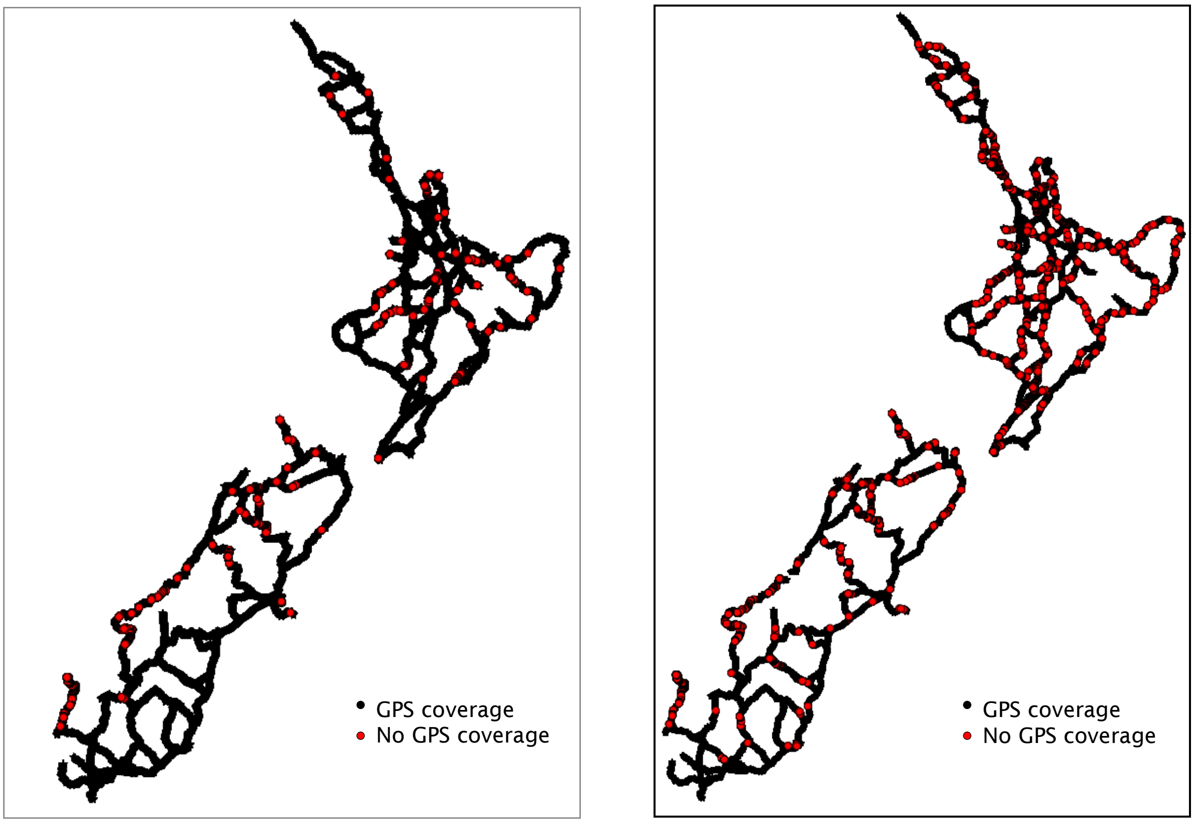


Table B.9 Route stations known to have poor GPS coverage

NMA	State Highway & Route Station	Road ID	Description
Central Otago	SH6-RS814	799	Haast/Wanaka
Central Otago	SH84-RS0-I	894	Wanaka/Albert Town
East Waikato	SH25-RS42	1565	Thames/Coromandel
PSMC005	SH16-RS19/7.87	264	Hobsonville/Massey
PSMC005	SH16-RS19/4.49	1737	Hobsonville/Massey
Southland	SH94-RS192	929	Te Anau/Milford Sound
Southland	SH94-RS197	930	Te Anau/Milford Sound
Southland	SH94-RS212	931	Te Anau/Milford Sound
Southland	SH94-RS229	932	Te Anau/Milford Sound
Southland	SH94-RS240	933	Te Anau/Milford Sound
Southland	SH94-RS241	934	Te Anau/Milford Sound
West Coast	SH6-RS783	575	Haast/Wanaka
West Coast	SH6-RS800	576	Haast/Wanaka
West Coast	SH6-RS169	579	Reefton/Springs Junction

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Appendix C: HMI designs shown to focus groups

Figure C.1 Change in speed zone

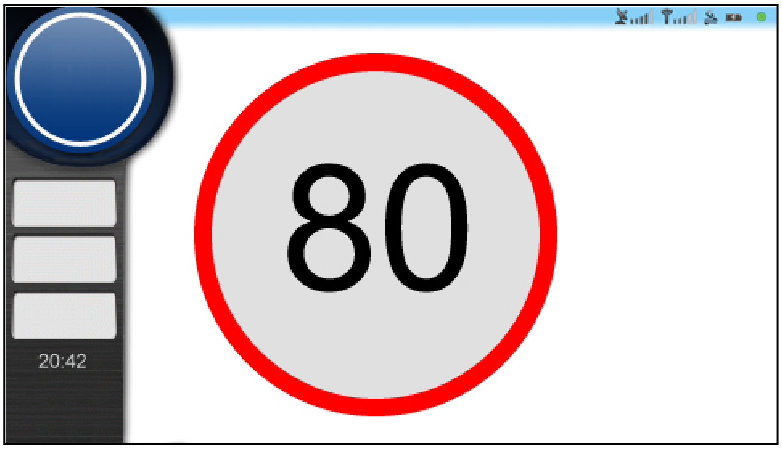


Figure C.2 Change in speed zone (night view)

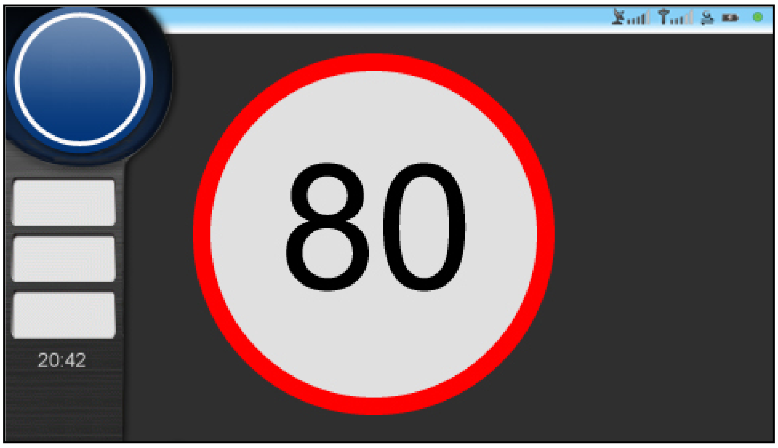


Figure C.3 Exceeding speed zone limit

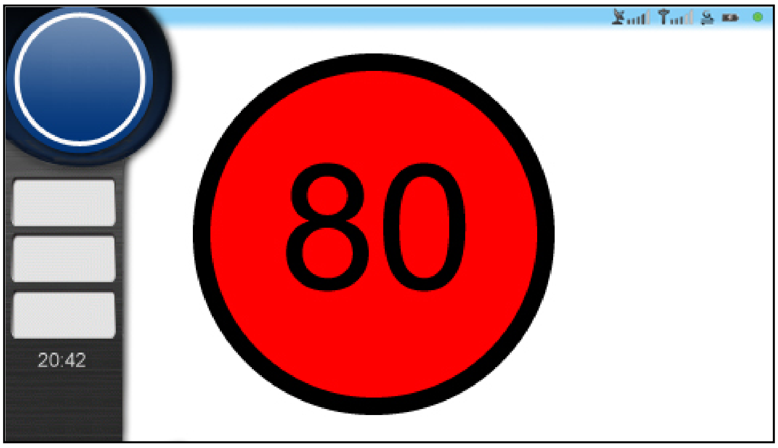


Figure C.4 Advisory warning

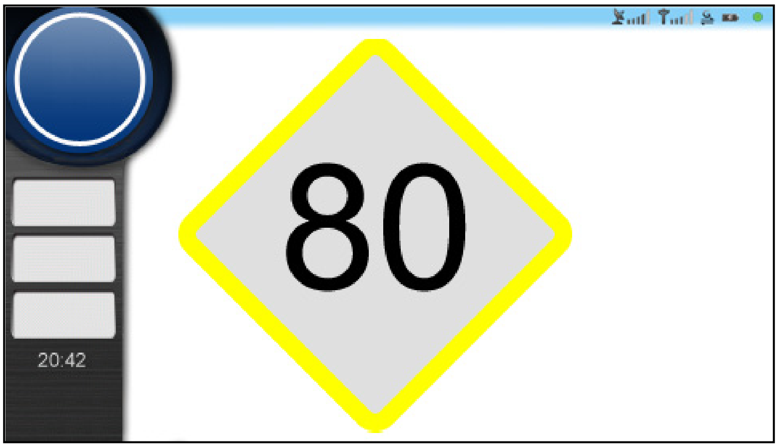


Figure C.5 Advisory warning and exceeding speed zone limit

Figure C.6 Alternative advisory warning (side-by-side yellow diamond)

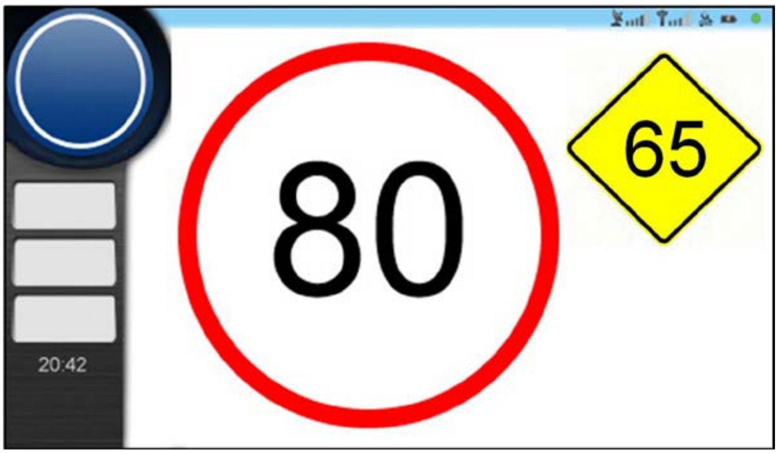


Figure C.7 Alternative advisory warning (side-by-side pictorial)

Appendix D: Field trial recruitment and participant questionnaires

D.1 Automobile Association recruitment email

Dear AA Member

At present there is a research project going on in your area which requires the assistance of drivers. This project is part of the New Zealand Transport Agency's Safety Research and is an investigation into the deployment of Intelligent Speed Adaptation (ISA) technology in New Zealand. ISA is a system that monitors driver speed in comparison to recommended speeds to provide real-time feedback to drivers. This system has been tested internationally and this is your chance to be a part of the New Zealand trial.

The project uses field trials and surveys which have the following aims:

- to explore the impact of ISA on driver behaviour
- to understand the perceptions of users.

Who can help?

We are looking for volunteers who:

- hold a valid full New Zealand Drivers Licence
- have a car available for use in the trial
- are available to participate on at least one weekend or weekday in February or March 2012
- are willing to visit Opus Central Laboratories in Gracefield to participate in the field trial, consisting of three driving circuits each taking around 1 hour and 15 minutes to complete (an approximately 6-hour time commitment in total)

You will be reimbursed with $250 MTA vouchers for completion of the exercise as a show of appreciation of your time and to cover the cost of petrol for the trial.

Please note all information provided during the field trial will be kept anonymous and is for research purposes only.

What should volunteers, or people interested in volunteering, do?

If you, or a family member(s) or friend(s) are interested in taking part this important study, please contact Kate Mora, Opus Central Laboratories at Kate.Mora@opus.co.nz. Places in the study are limited so please contact us as soon as possible.

D.2 Information sheet for participants

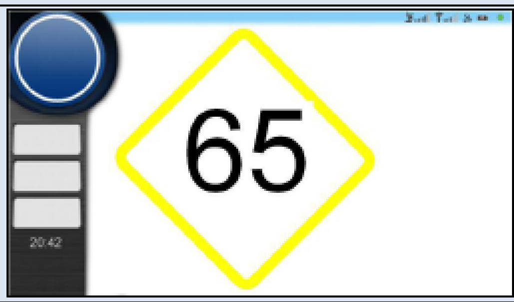
INTELLIGENT SPEED ADAPTATION FIELD TRIAL
BACKGROUND INFORMATION

Intelligent Speed Adaptation (ISA) refers to a type of system that monitors vehicle speeds compared to local speed limits or speed advisories. Such systems can either be advisory (warning the driver through sounds or visual displays) or perform interventions such as automatically slowing the vehicle.

The main purpose of ISA systems is to assist the driver to follow speed limit advice at all times, even when driving through new areas or those with variable speed limits (e.g. when driving through a school zone). A portable ISA device can be plugged into your vehicle to provide real-time visual and audio feedback.

An example of an ISA device.

In the field trials, you will be trialling the advisory ISA type. These are the systems that provide the information to the driver about the speed limit and their current speed but allow the driver to make their own decisions about what they do with this information. They do not override the wishes of the driver.

Examples of the types of advisories that could be provided	
	
Standard speed advisory	*Curve advisory*

There are potential benefits of ISA including reduced accident risk, reduced noise and exhaust emissions, and increased fuel efficiency. Focus groups exploring the deployment of ISA in a New Zealand context have been generally supportive of the technology, however further exploration into the perceptions of actual users is required.

We want to know how you react while using it in your own vehicle and your perceptions of the experience. Further information regarding the trial will be sent to you if you meet the selection criteria to participate.

D.3 Screening questionnaire

Intelligent Speed Adaptation Field Trial: Screening questionnaire

1. Do you have a current, full New Zealand drivers license? YES ☐ NO ☐

2. Do you have a car you drive regularly available for use in the trial? YES ☐ NO ☐

3. Does this car have a working cigarette lighter? YES ☐ NO ☐

4. What is your age group?

18-24 years	☐
25-29 years	☐
30-34 years	☐
35-39 years	☐
40-44 years	☐
45-49 years	☐
50-54 years	☐
55-59 years	☐
60-64 years	☐
65 years and over	☐

5. What is your gender? MALE ☐ FEMALE ☐

6. Exceeding the 100 kph speed limit on the motorway would be... **(please check one number per line)**

	1	2	3	4	5	6	7	
Unsafe	☐	☐	☐	☐	☐	☐	☐	Safe
Useful	☐	☐	☐	☐	☐	☐	☐	Useless
Unsatisfying	☐	☐	☐	☐	☐	☐	☐	Satisfying
Beneficial	☐	☐	☐	☐	☐	☐	☐	Harmful
Not enjoyable	☐	☐	☐	☐	☐	☐	☐	Enjoyable
Positive	☐	☐	☐	☐	☐	☐	☐	Negative
Reckless	☐	☐	☐	☐	☐	☐	☐	Cautious
Good	☐	☐	☐	☐	☐	☐	☐	Bad

7. I would intend to exceed the 100 kph speed limit on a motorway... **(please check one number only)**

	1	2	3	4	5	6	7	
Strongly disagree	☐	☐	☐	☐	☐	☐	☐	Strongly agree

8. I would want to exceed the 100 kph speed limit on a motorway... **(please check one number only)**

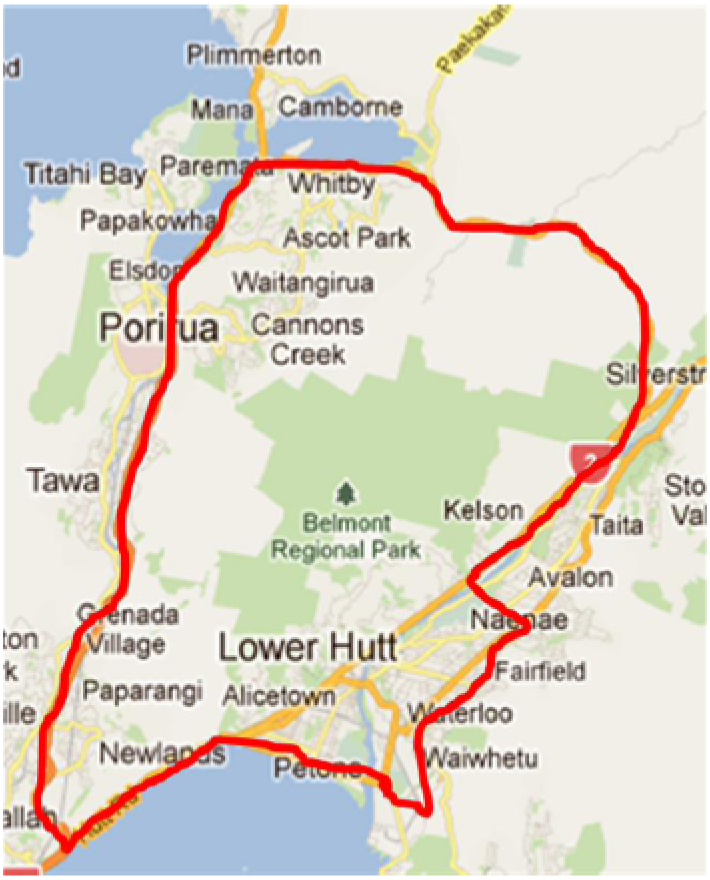
	1	2	3	4	5	6	7	
Strongly disagree	☐	☐	☐	☐	☐	☐	☐	Strongly agree

9. I would plan to exceed the 100 kph speed limit on a motorway... **(please check one number only)**

	1	2	3	4	5	6	7	
Definitely would not	☐	☐	☐	☐	☐	☐	☐	Definitely would

10. Would you be comfortable driving the route shown on the following page? YES ☐ NO ☐

Field trial route map



The circuit will begin at Opus Central Laboratories, 138 Hutt Park Road, Gracefield. Participants are to exit Central Labs and:

- Turn right onto Hutt Park Road,
- Follow Hutt Park Road to the end, turning left onto Gracefield Road,
- Turn right onto Bell Road,
- Follow Bell Road and continue onto Waiwhetu Road,
- Follow Waiwhetu Road and continue onto Naenae Road,
- Turn left on Daysh Street,
- Follow Daysh Street to the roundabout and continue forward onto Fairway Drive,
- Turn right onto State Highway 2,
- Turn left onto State Highway 58 (Haywards Hill Road),
- At the roundabout, continue left on State Highway 58,
- Follow State Highway 58 to the end, turning left onto State Highway 1 (at Paremata),
- Turn left onto State Highway 2 (Hutt Road),
- Take the Petone/Seaview exit from State Highway 2, exiting the roundabout onto The Esplanade,
- Follow The Esplanade to the end and continue onto Waione Street,
- Exit the Waione Street roundabout onto Seaview Road,
- Turn left onto Parkside Road, and
- Turn right onto Hutt Park Road, finishing back at Central Labs

D.4 Pre-trial questionnaire

Before you complete any runs of the road trial route, we would like to know your first impressions of the ISA system and the effect it will have on your driving.

Thinking about the video of the ISA device that you have just been shown, please indicate your level of agreement with the following statements

		Strongly disagree	Disagree	Not sure/ neutral	Agree	Strongly agree
1.	Using the ISA system will be frustrating	☐	☐	☐	☐	☐
2.	I feel the ISA system will be an invasion of my personal freedom	☐	☐	☐	☐	☐
3.	I will find the ISA system useful when I drive	☐	☐	☐	☐	☐
4.	Driving with the ISA system will be fun	☐	☐	☐	☐	☐
5.	I will drive more safely with the ISA system	☐	☐	☐	☐	☐
6.	The ISA system will be effective in reducing my speed	☐	☐	☐	☐	☐
7.	Using the ISA system will improve my driving performance	☐	☐	☐	☐	☐
8.	I trust the ISA system to provide the correct speed information	☐	☐	☐	☐	☐
9.	The ISA system will be distracting when driving	☐	☐	☐	☐	☐
10.	Using the ISA system will make it easier to drive	☐	☐	☐	☐	☐
11.	Using the ISA system will make me pay more attention to my speedometer	☐	☐	☐	☐	☐
12.	I feel like I will be driving on auto-pilot with the ISA system	☐	☐	☐	☐	☐

We would also like to know about your general attitudes to speed. Please indicate your level of agreement with the following statements

		Strongly disagree	Disagree	Not sure/ neutral	Agree	Strongly agree
13.	There isn't much chance of an accident when speeding if you are careful	☐	☐	☐	☐	☐
14.	The risk of being caught speeding is small	☐	☐	☐	☐	☐
15.	Penalties for speeding are not very severe	☐	☐	☐	☐	☐
16.	Most people who get caught speeding are just unlucky	☐	☐	☐	☐	☐
17.	Enforcing the speed limit helps lower the road toll	☐	☐	☐	☐	☐
		Dislike very much	Dislike	Neutral	Like	Like very much
18.	How much do you like driving fast on the open road?	☐	☐	☐	☐	☐

19. Speed limits on the roads that I normally use are...

☐ Too low	☐ Too high	☐ About right

We also want to know your opinions on hazard advisory signs for upcoming curves. Please indicate your level of agreement with the following statements						
		Strongly disagree	**Disagree**	**Not sure/ neutral**	**Agree**	**Strongly agree**
20.	Curve advisories are just a recommendation	☐	☐	☐	☐	☐
21.	I don't need to drive as slowly around curves as other drivers	☐	☐	☐	☐	☐
22.	Only unconfident drivers drive at the advisory speed around curves	☐	☐	☐	☐	☐
23.	Experts set the speed advisories at curves so I trust them as accurate	☐	☐	☐	☐	☐
24.	Curve advisories are set for trucks, not regular vehicles	☐	☐	☐	☐	☐

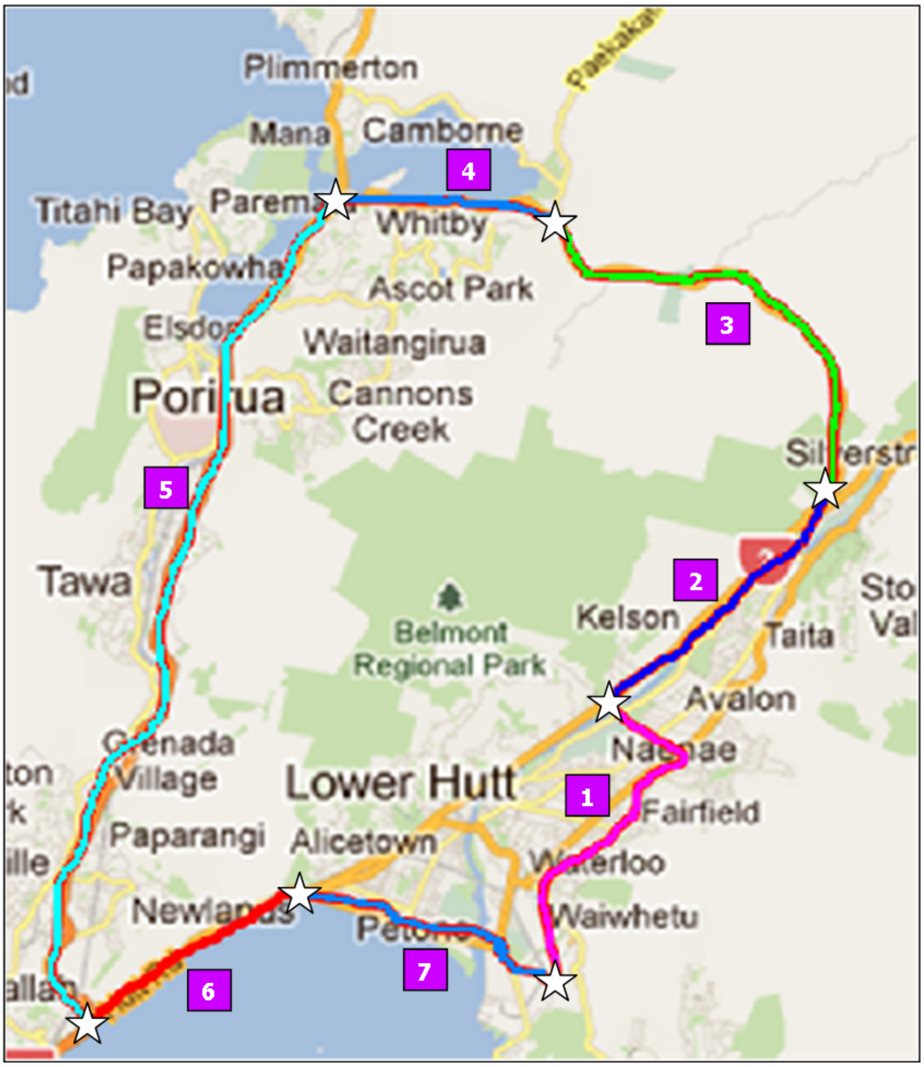
Thank you for your answers and enjoy your first run

D.5 Post-trial baseline questionnaire

You have now just completed a run of the road trial route with **no ISA device feedback**. We would like to know a bit about how you felt you drove on the run you just completed

1. How would you best describe your overtaking behaviour on the run you just completed? Your best guess is fine		
☐ I overtook others more than I was overtaken	☐ I was overtaken more than I overtook others	☐ It was about equal

2. We have divided the route you took into 7 different segments (see the map below). For each segment, please indicate the percentage of time you felt you were travelling at your own speed, not affected by the vehicles around you. Again, your best guess is fine	
Section 1: Central Laboratories to State Highway 2 (SH2)	%
Section 2: SH2 to turn off to SH58 at Haywards	%
Section 3: Start of SH58 to the roundabout at Pauatahanui	%
Section 4: SH58 roundabout to SH1	%
Section 5: SH1 to SH2 interchange	%
Section 6: SH2 from interchange to turn off to Petone foreshore	%
Section 7: Petone foreshore to Central Laboratories	%



D.6 Post-trial fixed questionnaire

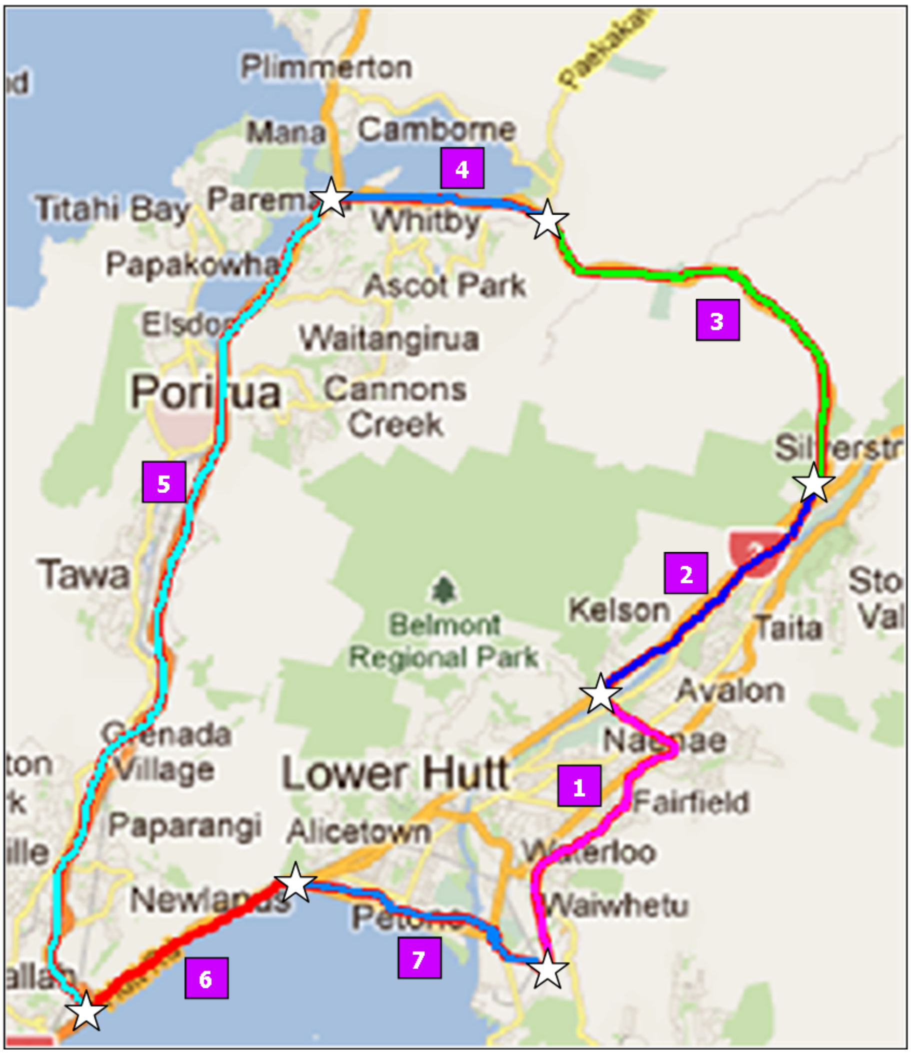
You have now just completed a run of the road trial route with the **fixed ISA system**. We would like to know a bit about how you felt about the system you just used and how you think it affected your driving

1. How would you best describe your overtaking behaviour on the run you just completed? Your best guess is fine

☐ I overtook others more than I was overtaken	☐ I was overtaken more than I overtook others	☐ It was about equal

2. We have divided the route you took into 7 different segments (see the map below). For each segment, please indicate the percentage of time you felt you were travelling at your own speed, not affected by the vehicles around you. Again, your best guess is fine

Section 1: Central Laboratories to State Highway 2 (SH2)	%
Section 2: SH2 to turn off to SH58 at Haywards	%
Section 3: Start of SH58 to the roundabout at Pauatahanui	%
Section 4: SH58 roundabout to SH1	%
Section 5: SH1 to SH2 interchange	%
Section 6: SH2 from interchange to turn off to Petone foreshore	%
Section 7: Petone foreshore to Central Laboratories	%



Thinking about the last run you completed, please indicate how the fixed ISA system affected the following						
		Decreased significantly	Decreased some	Neutral	Increased some	Increased significantly
3.	Travel time	☐	☐	☐	☐	☐
4.	Probability of being fined	☐	☐	☐	☐	☐
5.	Your attentiveness in traffic	☐	☐	☐	☐	☐
6.	Following distances	☐	☐	☐	☐	☐
7.	Ease of overtaking	☐	☐	☐	☐	☐
8.	Tendency to obey speed limits	☐	☐	☐	☐	☐
9.	Fuel consumption	☐	☐	☐	☐	☐
10.	Comfort of the driving task	☐	☐	☐	☐	☐
11.	Enjoyment of the driving task	☐	☐	☐	☐	☐
12.	Your ability to avoid dangerous situations (near misses)	☐	☐	☐	☐	☐

Thinking again about the run you just completed with the fixed ISA device, please indicate your level of agreement with the following statements						
		Strongly disagree	Disagree	Not sure/ neutral	Agree	Strongly agree
13.	Using the fixed ISA system was frustrating	☐	☐	☐	☐	☐
14.	I felt the fixed ISA system was an invasion of my personal freedom	☐	☐	☐	☐	☐
15.	I found the fixed ISA system useful when I drove	☐	☐	☐	☐	☐
16.	Driving with the fixed ISA system was fun	☐	☐	☐	☐	☐
17.	I drove more safely with the fixed ISA system	☐	☐	☐	☐	☐
18.	The fixed ISA system was effective in reducing my speed	☐	☐	☐	☐	☐
19.	Using the fixed ISA system improved my driving performance	☐	☐	☐	☐	☐
20.	I trusted the fixed ISA system to provide the correct speed information	☐	☐	☐	☐	☐
21.	The fixed ISA system was distracting when driving	☐	☐	☐	☐	☐
22.	Using the fixed ISA system will make it easier to drive	☐	☐	☐	☐	☐
23.	Using the fixed ISA system made me pay more attention to my speedometer	☐	☐	☐	☐	☐
24.	I felt like I was driving on auto-pilot with the ISA system	☐	☐	☐	☐	☐

The next series of questions are designed to get a feel for how user-friendly you found the fixed ISA system. Here, think about how easy it was to use the system you had on your last run and please indicate your level of agreement with the following statements						
		Strongly disagree	Disagree	Not sure/ neutral	Agree	Strongly agree
25.	The system was easy to use	☐	☐	☐	☐	☐
26.	The visual warnings were easy to understand	☐	☐	☐	☐	☐
27.	The visual warnings were irritating	☐	☐	☐	☐	☐
28.	The auditory warnings were easy to understand	☐	☐	☐	☐	☐
29.	The auditory warnings were irritating	☐	☐	☐	☐	☐
30.	The auditory warnings were easy to hear and distinguish from other sounds	☐	☐	☐	☐	☐
31.	I received enough warning of the upcoming speed limit changes	☐	☐	☐	☐	☐

32. If this fixed ISA came as standard equipment in your vehicle, but its use was optional, would you use it?		
☐ Yes, with its current design (survey completed, stop here)	☐ Yes, with some design changes (go to Q33)	☐ No (go to Q34)

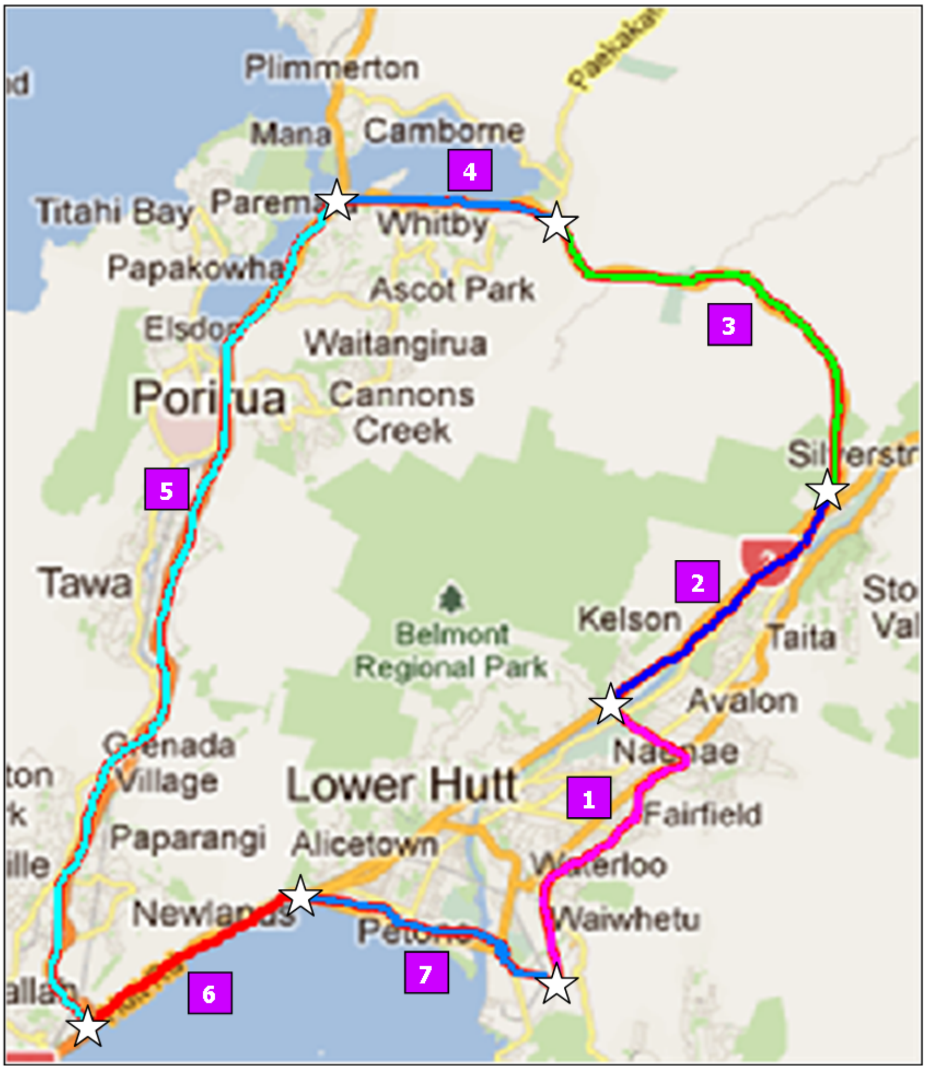
33. If you were to change something about the fixed ISA device to make it more user-friendly, what would you change?

34. What is the main reason you would not want to use the fixed ISA device?

D.7 Post-trial variable questionnaire

You have now just completed a run of the road trial route with the **variable ISA system**. We would like to know a bit about how you felt about the system you just used and how you think it affected your driving		
1. How would you best describe your overtaking behaviour on the run you just completed? Your best guess is fine		
☐ I overtook others more than I was overtaken	☐ I was overtaken more than I overtook others	☐ It was about equal

2. We have divided the route you took into 7 different segments (see the map below). For each segment, please indicate the percentage of time you felt you were travelling at your own speed, not affected by the vehicles around you	
Section 1: Central Laboratories to State Highway 2 (SH2)	%
Section 2: SH2 to turn off to SH58 at Haywards	%
Section 3: Start of SH58 to the roundabout at Pauatahanui	%
Section 4: SH58 roundabout to SH1	%
Section 5: SH1 to SH2 interchange	%
Section 6: SH2 from interchange to turn off to Petone foreshore	%
Section 7: Petone foreshore to Central Laboratories	%



Thinking about the last run you completed, please indicate how the variable ISA system affected the following						
		Decreased significantly	Decreased some	Neutral	Increased some	Increased significantly
3.	Travel time	☐	☐	☐	☐	☐
4.	Probability of being fined	☐	☐	☐	☐	☐
5.	Your attentiveness in traffic	☐	☐	☐	☐	☐
6.	Following distances	☐	☐	☐	☐	☐
7.	Ease of overtaking	☐	☐	☐	☐	☐
8.	Tendency to obey speed limits	☐	☐	☐	☐	☐
9.	Fuel consumption	☐	☐	☐	☐	☐
10.	Comfort of the driving task	☐	☐	☐	☐	☐
11.	Enjoyment of the driving task	☐	☐	☐	☐	☐
12.	Your ability to avoid dangerous situations (near misses)	☐	☐	☐	☐	☐
13.	Ability to safely negotiate curves	☐	☐	☐	☐	☐

Thinking again about the run you just completed with the variable ISA device, please indicate your level of agreement with the following statements						
		Strongly disagree	Disagree	Not sure/ neutral	Agree	Strongly agree
14.	Using the variable ISA system was frustrating	☐	☐	☐	☐	☐
15.	I felt the variable ISA system was an invasion of my personal freedom	☐	☐	☐	☐	☐
16.	I found the ISA system useful when I drove	☐	☐	☐	☐	☐
17.	Driving with the variable ISA system was fun	☐	☐	☐	☐	☐
18.	I drove more safely with the variable ISA system	☐	☐	☐	☐	☐
19.	The variable ISA system was effective in reducing my speed	☐	☐	☐	☐	☐
20.	Using the variable ISA system improved my driving performance	☐	☐	☐	☐	☐
21.	I trusted the variable ISA system to provide the correct speed information	☐	☐	☐	☐	☐
22.	The variable ISA system was distracting when driving	☐	☐	☐	☐	☐
23.	Using the variable ISA system made it easier to drive	☐	☐	☐	☐	☐
24.	Using the variable ISA system made me pay more attention to my speedometer	☐	☐	☐	☐	☐
25.	I felt like I was driving on auto-pilot with the variable ISA system	☐	☐	☐	☐	☐

The next series of questions are designed to get a feel for how user-friendly you found the variable ISA system. Here, think about how easy it was to use the system you had on your last run and please indicate your level of agreement with the following statements

		Strongly disagree	Disagree	Not sure/ neutral	Agree	Strongly agree
26.	The system was easy to use	☐	☐	☐	☐	☐
27.	The visual warnings were easy to understand	☐	☐	☐	☐	☐
28.	The visual warnings were irritating	☐	☐	☐	☐	☐
29.	The auditory warnings were easy to understand	☐	☐	☐	☐	☐
30.	The auditory warnings were irritating	☐	☐	☐	☐	☐
31.	The auditory warnings were easy to hear and distinguish from other sounds	☐	☐	☐	☐	☐
32.	I received enough warning of the upcoming speed limit changes	☐	☐	☐	☐	☐
33.	I received enough warning of the upcoming hazard advisories	☐	☐	☐	☐	☐

34. If this variable ISA came as standard equipment in your vehicle, but its use was optional, would you use it?

☐ Yes, with its current design (survey completed, stop here)	☐ Yes, with some design changes (go to Q35)	☐ No (go to Q36)

35. If you were to change something about the variable ISA device to make it more user-friendly, what would you change?

36. What is the main reason you would not want to use the variable ISA device?

D.8 Post-trial questionnaire

Now that you have completed all 3 runs, we have a few questions about your overall impression of the ISA technology you have tested today.

1. Thinking about the variable ISA device, which of the following other hazards would you like to see integrated into future versions of the device?	
☐ Railway crossings	☐ School zones
☐ Curves without advisory speeds signposted	☐ Shopping areas
☐ Bus stops	☐ Temporary speed zones (e.g. roadworks)
☐ None of these	☐ Other (please specify) ____________________

2. Which of the following groups do you think would benefit from having some form of ISA device in their vehicle? Tick all that apply (if any)	
☐ Novice drivers	☐ Young drivers (e.g. under 25 years old)
☐ Elderly drivers	☐ Professional drivers
☐ Speed offenders	☐ None of these
☐ Other (please specify) ____________________	

Next, we have a few questions about hand positions when driving

	The figure above shows examples of three common steering wheel hand positions. In your opinion, which of the three hand positions best shows:	**Two hands**	**One hand**	**Zero hands**
3.	Your typical hand positions when driving	☐	☐	☐
4.	The hand positions that will give you most control over the vehicle	☐	☐	☐
5.	The most natural hand positions when driving	☐	☐	☐
6.	Your hand positions when relaxed	☐	☐	☐
7.	Your hand positions when tense	☐	☐	☐

8. What types of in-vehicle devices do you use on a regular basis? (tick all that apply)	
☐ I don't use any devices	☐ Radio
☐ GPS navigation device (e.g. Navman)	☐ Hands-free mobile phone
☐ iPod or other music player	☐ Other (please specify) ____________________

9. Do you ever drive a company vehicle?		
☐ Yes, I drive my own company vehicle	☐ Yes, I sometimes drive someone else's company vehicle	☐ No, I never drive any company vehicles

10. How long have you had a drivers licence?					
☐ 0-2 years	☐ 2-5 years	☐ 5-10 years	☐ 10-15 years	☐ 15-20 years	☐ 20 years +

11. A typical privately-owned motor vehicle would travel about 14,000 kilometres each year. Please estimate how far you travel in your private motor vehicle each year?	
☐ 1-5000km	☐ 5-10000km
☐ 10-15000km	☐ 15-20000km
☐ 20-25000km	☐ 25-30000km
☐ 30-35000km	☐ More than 35000km

12. Where do you do most of your driving?		
☐ Mainly urban/suburban roads	☐ Mainly open/rural roads	☐ Both urban/suburban and open/ rural roads

13. How familiar with the test route were you prior to today's trials?		
☐ Very familiar (e.g. drive it regularly)	☐ Somewhat familiar (e.g. have driven it occasionally)	☐ Not familiar at all (e.g. have never driven it)

14. Finally, if you have any additional comments, please include them here

Appendix E: Stakeholder consultation on institutional and legislative barriers

E.1 Enquiry email sent to some governmental and non-governmental stakeholders

Text of the enquiry e-mail sent to the Ministry of Transport (as an example of similar e-mails sent to a number of organisations):

> *As you may know, Opus International Consultants, Central Laboratories undertakes research and is part of a consortium carrying out research for the New Zealand Transport Agency to investigate the possible future deployment of a vehicle based advisory Intelligent Speed Adaptation (ISA) system in New Zealand.*
>
> *It must be stressed that this is a research project and there is no proposal on anybody's table at present for the implementation of any ISA system in New Zealand.*
>
> *Advisory ISA involves displaying the speed limit to the driver and reminding the driver of changes in the speed limit, including in these study possible variable limits related to curves. It would be up to the individual driver to make decisions on receiving the advice and no information would be transmitted to any external party.*
>
> *There are various technologies which could be used for such a system and their use in vehicles could in theory range anywhere from voluntary to compulsory. Trial ISA systems have been associated overseas with reductions in road injury through better adherence to speed limits.*
>
> *Our study involves a small scale trial of such a system on a small part of the road network.*
>
> *Part of the work is to enquire of Central Government regarding any potential institutional, regulatory, or other barriers related to advisory ISA systems which might concern Central Government if implementation in some form in New Zealand was to be contemplated. If you have any such concerns in regard to this technology please relay them to me via email.*
>
> *Your concerns will be summarised in our report to the New Zealand Transport Agency.*

E.2 Comments of stakeholders on possible institutional or legislative barriers to advisory ISA

The following organisations were contacted to find out any concerns they might have about the voluntary advisory ISA system were it to be adopted in New Zealand:

Governmental

- The Ministry of Transport and the Ministry of Economic Development (representing Central Government)
- The Police
- Local Government New Zealand (LGNZ) (representing Local Government)

Non-governmental

- New Zealand Automobile Association (NZAA)
- Motor Industry Association (representing new-motor-vehicle importers)
- Imported Motor Vehicle Dealers Association Inc. (IMVDA) (representing used-motor-vehicle importers).

All these organisations were sent an e-mail based on the text in section E.1, with minor variations to adapt it to the particular organisation receiving the e-mail.

Their edited responses after various follow-up procedures are detailed in the following sections (only relevant responses are presented):

E.2.1 Ministry of Transport

E.2.1.1 Over reliance

Intelligent speed adaptation removes some of the driver's decision making about speed choices, shifting it to the system in the vehicle. Where the device shifts the responsibility of speed selection, drivers could rely on the system to manage speed. As a result, some drivers could use their vehicles with far less attention due to the partial automation of the driving task.

Based on this, drivers could reduce their visual, cognitive and auditory attentive capacity where the driving task is reduced. In saying that, we recognise the converse situation that too many driving tasks can also lead to driver distraction and inattention.

In addition, it is possible that using ISA could result in the driver completely relying on the speed limit indicated by the system, and insufficiently observing the real-time circumstances, such as wet weather.

Further work would be needed to identify the impact of over-reliance on ISA devices.

E.2.1.2 Legal liability issues

A range of safety-based ITS devices aim to reduce the responsibility of the driving task away from the driver towards in-vehicle and network-based devices. As the driving responsibility shifts, drivers will need to determine the extent to which drivers remain liable when an accident occurs. [Not sure if the intention is to reduce responsibility, it's more about helping the driver to manage their responsibilities. Also take care not to lump advisory and mandatory systems together].

Further research around where the legal liability occurs when vehicles are equipped with devices such as ISA would be needed.

E.2.1.3 Technical problems and device reliability

There are significant risks associated with the deployment of ISA in managing vehicle speeds. This is mainly due to the technical nature of the devices and the need to transfer information wirelessly between the vehicle and the road. In addition, ISA is dependent on the real-time transfer of information to support speed adjustment. A failure to adjust speed in real time could result in serious road safety outcomes.

The literature has identified various technical problems that could reduce the road safety impact of ISA on our roads. These include the following issues:

- Misreading speed limits is a technical problem that is inherent to the system programming. This mostly occurs on smaller streets or areas that have undergone changes due to construction.
- Signal can be lost under bridge bypasses and in areas with many high-rises.

- The placement of the system (onboard computer) has better connectivity when it is placed higher in the vehicle as opposed to under the dash.
- There can be a delay in pick-up for manual override.

Issues associated with the technical capacity of these devices would need to be fleshed out further.

E.2.1.4 Frequency bandwidths

The functioning of some ITS devices relies on radio frequencies to transfer information between systems. For example, ISA would rely on radio frequency to transmit information from roadside systems to indicate legal speed limits.

Given that ISA must operate in real time, interference of the transmission of information, in particular the radio signal, could result in the failure of the device to regulate the drivers speed. In addition, if the driver becomes inattentive due to the shift in driving task and there is a systems failure, this could lead to a crash.

E.2.2 The New Zealand Police

The Police would have some issue with any system where a GPS-derived speed display in the vehicle was promoted as being accurate (given that GPS uses averages to determine speed and might vary from radar). Police would also not support inaccurate mapping; so any mapping would also have to include a provision for timely updates, etc.

E.2.3 Local Government New Zealand

Vehicle policy and regulation is generally considered to be a function of central government as opposed to local government. Local government is responsible for setting speed limits on local roads (including related signage) and as such, any proposed trials that may take place on local roads should be undertaken in consultation with the local road controlling authority in question.

E.2.4 The New Zealand Automobile Association (NZAA)

The NZAA comments related to driver behaviour and the practicalities of implementation. It was felt that key issues would be the possibility of driver distraction and driver annoyance. Some GPS systems are more human-centric than others and testing on real drivers was advocated. Concern was expressed about the applicability of advisory cornering speeds to different vehicle/driver/environmental combinations and how they could be made to work for motorcycles. There were also practical concerns regarding how ISA could be made to cope with temporary restrictions, such as those at roadworks, and variable school speed zones. It was also felt that if ISA was to become compulsory, it would likely be opposed by members who might perceive it as ‘nagware’.

Some specific points made were:

- A risk with ISA is it is a subtle signal to drive ‘to the speed limit’, undermining the recommendation to drive at a ‘speed appropriate to the conditions’. However, it does correct unintentional speeding.
- The question for drivers using Intelligent Speed Adaption is ‘how intelligent is it?’ How much of the driver’s intelligence is being supplanted by a device? Does the driver know how much she or he should rely on the device? Are the limitations of the advice obvious in its user interface?
- The risk of driver distraction by the ISA will depend strongly on the design. Designs must be based on an underlying understanding of human thought processing and be tested with real drivers. There have already been crashes because the focus of the driver has shifted from the driving environment to

driving instruments (eg navigation systems). As in aviation, instruments are intended to assist the pilot or driver to make judgements, not to supplant human beings

- Simulation studies have found drivers do not necessarily consciously read speed limit or speed advisory signs. They drive, just as they walk, on auto-pilot. Given the rate of crashes, it is clear the human driving processor is, within normal tolerances, pretty good. Interrupting this processor to provide information should therefore only occur when the information might not normally be available from the environment.
- Intelligent Speed Adaption may have a role to play where drivers' ability is not within normal tolerances. This may include learning drivers. It may also have a useful educative purpose over time. However the AA believes that following the learning from the aviation industry regarding the human–machine interface, it should always be clear who is in control of a craft at any time. Ambiguity in this respect must be avoided at all costs.

E.2.5 Motor Industry Association (MIA) (representing new-vehicle importers)

With regard to ISA there would be no issue around voluntary implementation – this is happening now. If any form of regulatory control was suggested then the MIA would require input around what technology was used, how this would be implemented (ie as Original Equipment (OE) or after-market), the time frame, etc, as well as also needing to ensure the same provisions applied to used-vehicle imports.

E.2.6 Imported Motor Vehicle Dealers Association (IMVDA) (representing used-vehicle importers)

Verbal discussions indicated that this group would be anxious to have input at an early stage in the event of any future government proposals for changes to requirements regarding the fitting of technology to vehicles.

E.2.7 Ministry of Economic Development (MED)

E.2.7.1 Radio Communications Act (1989)

Any radio transmitter operated in New Zealand requires a licence under the Radiocommunications Act 1989, so if the ISA system has a transmitting feature, this would require a licence. It is an offence to transmit radio waves without a licence

E.2.7.2 Types of licensing

- *Individual licensing*: Many radio transmitters are licensed on an individual basis – mostly these are protected services such as cellular, AM/FM broadcasting, television broadcasting, etc. Typically a licence per transmitter is required and regulatory fees apply (see www.rsm.govt.nz/cms/licensees/fees/annual-fees).
- *General user licensing*: As it is not always practical or efficient to create individual licences, some radio transmitters and uses, such as consumer devices (Wifi cordless telephones, etc) are covered by General User Licences (GULs). If a transmitter is covered (within the terms and conditions) by a GUL, then individual licensing is not required. Some countries refer to this as 'licence exempt'. General User Licences have no protection from interference, nor can they cause interference to other licensed services.

Note that all equipment also needs to meet an appropriate standard prescribed in the Radio Standards notice (see www.rsm.govt.nz/cms/policy-and-planning/spectrum-policy-overview/legislation/gazette-notices/product-compliance/radiocommunications-radio-standards-notice-2010).

E.2.7.3 Allocations, bands planning and uses

New Zealand's radio frequency spectrum has been allocated and planned for certain uses – for example there are particular bands for radio broadcasting, television, cellular, etc. This planning and separation of services it vital to ensure economic, efficient and interference-free use of the spectrum.

New allocations and uses often require investigation, followed up with a consultation process. The consultation process can take a couple of years to conclude and if there are existing users in the band they may need to be moved, which can take five years or more.

E.2.7.4 Intelligent Transport Systems

The Ministry has been conducting some work with Intelligent Transport Systems (ITS) and looking at the 5.9GHz band.

Appendix F: Benefit–cost analysis

F.1 Data handling

Table F.1 shows the sectioning that was used for this analysis.

Table F.1 Analysis sections

Section number	Running distance start (m)	Running distance end (m)	Section length (m)	Speed limit (km/h)	Description
0	40	1040	1000	50	50km/h urban area
1	1040	2330	1290	50	50km/h urban traffic-calmed area
2	2330	7660	5330	50	50km/h urban area
3	7660	12,640	4980	100	100km/h rural expressway (multilane)
4	12,640	22,510	9870	100	100km/h rural single carriageway
5	22,510	26,010	3500	80	80km/h rural area
6	26,010	27,820	1810	50	50km/h urban area
7	27,820	29,790	1970	100	100km/h rural expressway (multilane)
8	29,790	42,600	12,810	100	100km/h rural motorway (multilane)
9	42,600	44,560	1960	80	80km/h rural expressway (Ngauranga Gorge) [excluded]
10	44,560	50,110	5550	100	100km/h rural expressway (multilane)
11	50,110	50,370	260	80	80km/h rural area [excluded]
12	50,370	55,450	5080	50	50km/h urban area

The data used in this analysis was the raw unfiltered data collected during the experimental trials, reported in chapter 8, with the following data removed:

- data for participant numbers 2, 5, 12 and 33 – these four participants each had at least 10% of at least one run missing, due to equipment malfunction
- the first 40m of data of the trial route, due to a data-processing error
- the last 10m of data of the trial route, as this data was missing for a number of participants due to variations in position over the route
- data from Ngauranga Gorge (section number 9), where a variable speed limit with a default of 80km/h was in place, and data from the short 260m 80km/h section (section number 11).

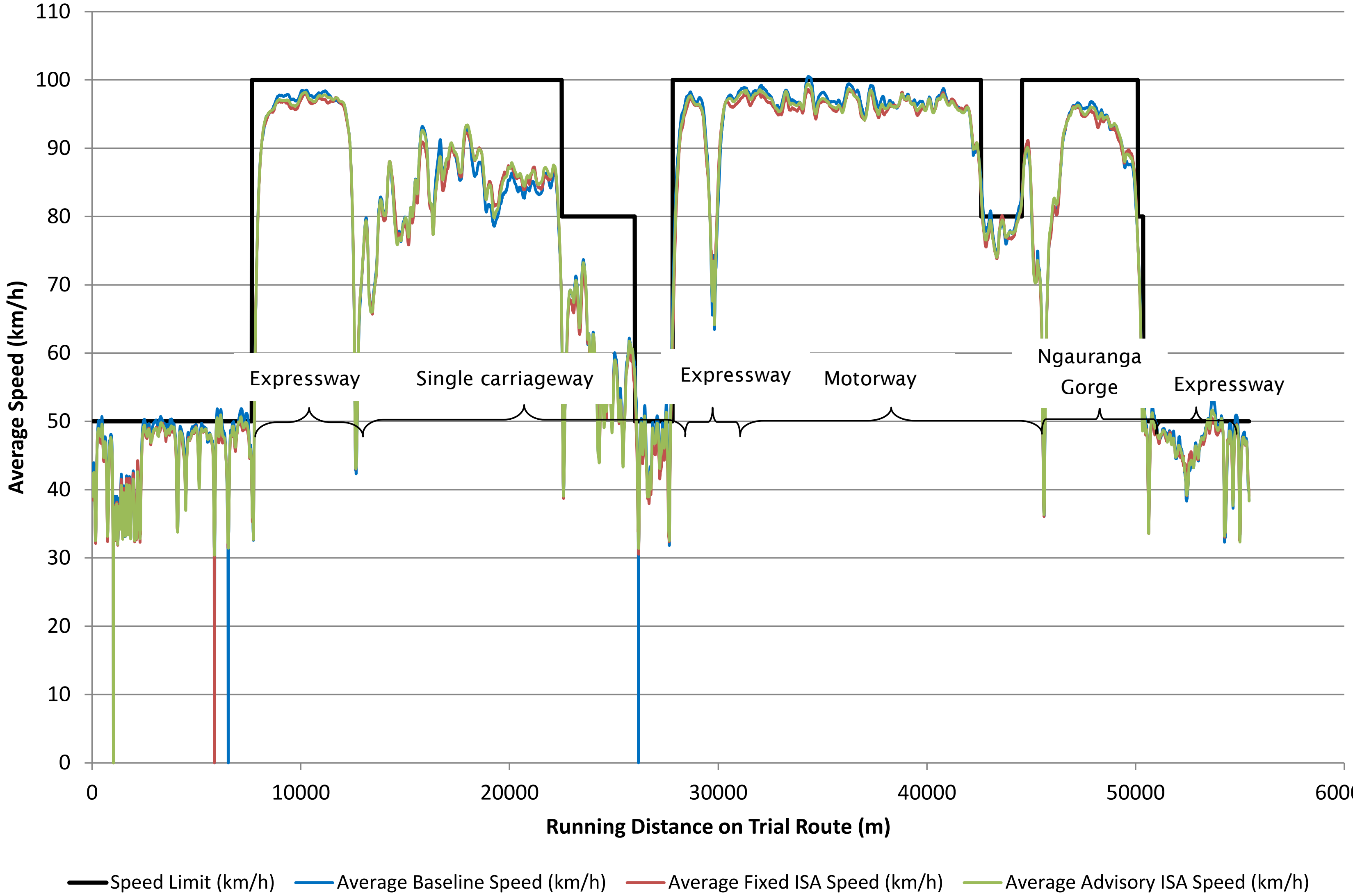
Also, as with the field trials (chapter 8), the raw GPS (time-based) data was converted to distance-based data by dividing the route into 10m sections and then assigning each GPS point to the 10m section that it fell within. GPS points within 50m of the carriageway were ‘snapped’ to the nearest 10m section on the route, and any points that lay outside of this 50m range were discarded. Similarly, any points relating to drivers deviating from the trial route were also discarded. Once each data point had been assigned, the 10m sections that did not have data assigned were populated from the previously populated 10m data point, with a maximum of two ‘empty’ 10m sections ‘filled’ in this way (if the ‘gap’ between GPS data points was greater than 30m, then no data was assigned to the next 10m point).

Speeds of less than 30km/h were removed from the dataset as an approximation of the free speed. The Kloeden models use free travelling speed defined as the speed of a vehicle moving along a midblock section of road, or with right of way through an intersection, and not slowing to join, or accelerating away from, a traffic stream; and the Taylor models use off-peak travel data.

F.2 Speed profiles on sections of the route used in the experimental trials

Figure F.1 on the next page shows the average speed of trial participants over the trial route.

Figure F.1 Average speed of trial participants over the trial route



F.3 Trial section statistics

Table F.2 Trial section statistics across each individual participant, by each 10m section of the trial route

ISA section	% speeding (visual ISA stimulus activated)			% speeding >3km/h above speed limit (audio + visual ISA stimulus activated)		
	Baseline	Fixed ISA	Variable ISA	Baseline	Fixed ISA	Variable ISA
All speed zones	19.9%	13.2%	13.4%	7.6%	4.4%	4.4%
• 50km/h urban	29.7%	18.1%	19.2%	12.0%	5.8%	5.8%
• 80km/h rural	0.9%	0.7%	1.9%	0.4%	0.0%	0.5%
• 100km/h rural	16.9%	5.9%	11.5%	3.6%	11.2%	3.9%
- 100km/h single-lane carriageway	2.1%	2.3%	2.9%	0.2%	0.4%	0.6%
- 100km/h expressway	15.9%	10.9%	10.1%	4.6%	3.4%	4.2%
- 100km/h motorway	16.9%	11.5%	11.2%	5.9%	3.6%	3.9%

F.4 Crash benefit results

F.4.1 Mean-speed crash risk models' (Nilsson/Elvik power model) crash benefits of fixed ISA

Plotting the change in mean speed achieved for the fixed ISA condition relative to the baseline condition (table F.3), there was a decrease in mean speed across all three speed limit zones, with greater reductions in the 50km/h and 80km/h zones than in the 100km/h zone. When the 100km/h zone was broken into sections for single and multilane carriageway, the single-lane carriageway section had a 0.3km/h increase in mean speed, and the multilane carriageway had a decrease of 0.6km/h. When the multilane carriageway sections were further disaggregated into expressway and motorway sections, there was a 0.6km/h decrease for both, even though their mean speeds were different.

Applying Nilsson's power model using the power factors developed by Elvik, expected crash reductions (table F.3) ranged from 0% for minor-injury crashes in a 100km/h speed limit zone to 5–6% for fatal crashes in 50km/h and 80km/h speed limit zones. When the single-lane carriageway road sections were separated from the 100km/h speed limit zone data, crash reductions of between 1% and 3% were expected.

Table F.3 Expected injury crash savings using Nilsson's power model and power factors from Cameron and Elvik (2010) for fixed ISA relative to the baseline

Road type	Harmonic mean speed		Speed difference (km/h)	Expected reduction in crashes		
	Baseline (V_{before}) (km/h)	Fixed ISA (V_{after}) (km/h)		Fatal crashes (%)	Serious-injury crashes (%)	Minor-injury crashes (%)
50km/h	45.8	44.9	-0.9	5%	3%	2%
80km/h	57.9	57.0	-0.9	6%	4%	2%
100km/h	89.5	89.3	-0.2	1%	1%	0%
• 100km/h single-lane carriageway	82.4	82.7	+0.3	-2%	-1%	0%
• 100km/h multilane carriageway	92.7	92.1	-0.6	3%	2%	1%
- 100km/h expressway	89.0	88.4	-0.6	3%	2%	1%
- 100km/h motorway	96.5	95.9	-0.6	3%	2%	1%

F.4.2 Mean-speed crash risk models' (Nilsson/Elvik power model) crash benefits of variable ISA

Summarising the change in mean speed achieved for the variable ISA condition relative the baseline condition (table F.4), there was a decrease in mean speed across the 80km/h and 50km/h speed limit zones, but there was a 0.4km/h increase in mean speed in 100km/h speed limit zones. Applying Nilsson's power model using the power factors developed by Elvik, expected crash reductions ranged from 5% in fatal crashes in the 50km/h and 80km/h speed limit zones, to -2% in fatal crashes in 100km/h speed limit zones. The crash risk increases in the 100km/h speed limit zone were due to increases experienced in the single-lane carriageway sections of the trial route, which showed crash risk increases of between 2% and 8%.

Table F.4 Expected injury crash savings using Nilsson's power model and power factors from Cameron and Elvik (2010) for variable ISA

Road type	Harmonic mean speed		Speed difference (km/h)	Expected reduction in crashes		
	Baseline (V_{before}) (km/h)	Advisory ISA (V_{after}) (km/h)		Fatal crashes (%)	Serious-injury crashes (%)	Minor-injury crashes (%)
50km/h	45.8	45.0	-0.8	5%	3%	2%
80km/h	57.9	57.2	-0.7	5%	3%	1%
100km/h	89.5	89.9	0.4	-2%	-1%	0%
• 100km/h single-lane carriageway	82.4	84.0	1.6	-8%	-5%	-2%
• 100km/h multilane carriageway	92.7	92.4	-0.3	1%	1%	0%
- 100km/h expressway	89.0	88.8	-0.2	1%	0%	0%
- 100km/h motorway	96.5	96.0	-0.5	2%	1%	1%

F.4.3 Mean speed and shape of speed distribution (Taylor et al models) crash benefits of fixed ISA

Applying the U1 and U2 models to the urban 50km/h sections of the trial route, and the EURO model to the single-lane carriageway 100km/h section (table F.5), there was an 8–15% reduction in all injury crashes under the U1 and U2 models for fixed ISA; and the EURO model predicted a 0% reduction in all injury crashes for 100km/h single-lane carriageway roads and a 5% reduction in all injury crashes for 80km/h single-lane carriageway roads.

Table F.5 also shows that the 50km/h roads had considerably more trial participants exceeding the speed limit than for the 100km/h and 80km/h single-lane carriageway sections. However, the greatest reduction in the mean speed of those exceeding the speed limit was for the 80km/h sections, with an increase recorded for the 100km/h single-lane carriageway sections.

Table F.5 Expected injury crash savings using models developed by Taylor et al (2000 & 2002; cited in Cameron & Elvik 2010) for fixed ISA relative to the baseline

Road type	Model used	Harmonic mean speed of those exceeding the speed limit		Speed difference	% exceeding the speed limit		Expected reduction in all injury crashes
		Baseline (Vex_{before}) (km/h)	Fixed ISA (Vex_{after}) (km/h)		Baseline (%)	Fixed ISA (%)	
50km/h	U1	n/a	n/a	n/a	n/a	n/a	8%
50km/h	U2	53.3	52.8	-0.5	25.7%	13.6%	15%
80km/h (single-lane carriageway)	EURO	83.4	81.6	-1.8	0.5%	0.3%	5%
100km/h single-lane carriageway	EURO	101.8	102.2	+0.4	1.2%	1.1%	0%

F.4.4 Mean speed and shape of speed distribution (Taylor et al models) crash benefits of variable ISA

For the variable ISA, the U1 and U2 models predicted a reduction in injury crashes of 8% and 13% respectively (table F.6). On the 100km/h single-lane carriageway the EURO model predicted a 3% increase in all injury crashes, and for the 80km/h section, a 10% increase in all injury crashes.

The difference in the mean speed of those exceeding the speed limit and the proportion exceeding the speed limit followed the same pattern as for the fixed ISA situation.

Table F.6 Expected injury crash savings using models developed by Taylor et al (2000 & 2002; cited in Cameron & Elvik 2010) for variable ISA

Road type	Model used	Harmonic mean speed of those exceeding the speed limit		Speed difference	% exceeding the speed limit		Expected reduction in all injury crashes
		Baseline (Vex_{before}) (km/h)	Variable ISA (Vex_{after}) (km/h)		Baseline (%)	Variable ISA (%)	
50km/h	U1	n/a	n/a	n/a	n/a	n/a	8%
50km/h	U2	53.3	52.9	-0.4	25.7%	14.2%	13%
80km/h (single-lane carriageway)	EURO	83.4	82.7	-0.7	0.5%	1.2%	-10%
100km/h single-lane carriageway	EURO	101.8	102.2	+0.4	1.2%	1.4%	-3%

F.4.5 Individual crash risk models' (Kloeden et al) crash benefits of fixed ISA

Applying the Kloeden et al (2001 and 2002) models for fixed ISA, the 50km/h area showed the greatest predicted reduction, in this instance in fatal and serious-injury crashes (22%). This was followed by the 80km/h area (9%), and variable results in the 100km/h sections, ranging from a 3% increase to a 6% reduction, with a 5% reduction overall.

Table F.7 Expected injury crash savings using models developed by Kloeden et al (2001 and 2001) for fixed ISA relative to the baseline

Road type	Model used	Harmonic mean baseline speed (km/h)	Expected fatal and serious-injury crash reduction (%)
50km/h	Kloeden, McLean and Glonek 2002	45.8	22%
80km/h	Kloeden, Ponte and McLean 2001	57.9	9%
100km/h		89.5	5%
• 100km/h single-lane carriageway	Kloeden, Ponte and McLean 2001	82.4	-3%
• 100km/h multilane carriageway		92.7	6%
- 100km/h expressway	Kloeden, Ponte and McLean 2001	89.0	5%
- 100km/h motorway		96.5	6%

F.4.6 Individual crash risk models' (Kloeden et al) crash benefits of variable ISA

The variable ISA showed a slightly different pattern. The greatest fatal and serious-injury crash reduction was expected on 50km/h roads; however, the 80km/h sections performed poorest overall (-4%), followed by the 100km/h sections (2%). Once again there was considerable variation within the 100km/h sections, ranging from a 14% increase for single-lane carriageway roads to a 5% reduction for multilane roads and motorways.

Table F.8 Expected injury crash savings using models developed by Kloeden et al (2001 and 2001) for variable ISA relative to the baseline

Road type	Harmonic mean baseline speed (km/h)	Expected fatal and serious-injury crash reduction (%)
50km/h	45.8	14%
80km/h	57.9	-4%
100km/h	89.5	2%
• 100km/h single-lane carriageway	82.4	-14%
• 100km/h multilane carriageway	92.7	5%
- 100km/h expressway	89.0	3%
- 100km/h motorway	96.5	5%

F.5 State Highway 58 rural advisory curve details

Table F.9 Curve advisory data for the rural section of SH58

Curve number		Displacement (m)				Curve direction	Length (m)	Radius (m)	Crossfall		Assessed 85th percentile speed (km/h)		PW 25 speed advisory sign (km/h)	Speed limit (km/h)
ISA trial curve	From start of SH58	From start of SH58		From start of ISA route					Adverse	%	Approach	Curve		
		Start	End	Start	End									
A	4	610	760	13,250	13,400	Left	150	147	N	4.1	97	65	75	100
	5	760	860	13,400	13,500	Right	100	160	N	6	93	70	75	100
B	10	1840	2070	14,480	14,710	Right	230	170	N	8.3	102	74	75	100
C	18	3690	3760	16,330	16,400	Left	70	156	N	7.5	107	71	75	100
	19	3800	4040	16,440	16,680	Right	240	242	N	8.3	103	86	75	100
D	24	6580	6880	19,220	19,520	Right	300	184	N	6.6	96	75	85	100
E	38	11,460	11,640	24,100	24,280	Right	180	54	N	5.8	91	44	45	80
	39	11,640	11,720	24,280	24,360	Left	80	56	N	6.2	82	45	45	80
F	41	11,790	11,880	24,430	24,520	Left	90	134	N	3.4	78	62	45	80
	42	11,880	11,960	24,520	24,600	Right	80	60	N	5.1	76	45	45	80
G	45	12,270	12,320	24,910	24,960	Left	50	69	N	4	68	48	35	80
	46	12,320	12,410	24,960	25,050	Right	90	97	N	7.5	66	58	35	80
H	47	12,480	12,730	25,120	25,370	Right	250	63	N	8.9	73	50	45	80
I	48	12,730	12,990	25,370	25,630	Left	260	44	N	10.1	75	43	35	80

F.6 Advisory curve risk calculation data

Table F.10 Curve advisory risk calculation data

Curve number		Curve geometric data				Estimated 85th percentile speed based on geometry		Measured 85th percentile curve negotiation speeds			Personal crash risk (curve crashes/100 million vehicle entries)			
ISA trial curve	From start of SH58	Length (m)	Radius (m)	Grade (%)	AADT (vpd)	Approach (km/h)	Curve (km/h)	Baseline (km/h)	Fixed ISA (km/h)	Variable ISA (km/h)	Baseline	At calculated 'safe' curve negotiation speed	Fixed ISA	Variable ISA
A	4	150	147	5.6	13,622	97	65	78.67	75.83	73.50	8.60	2.94	7.43	6.46
	5	100	160	8.7	13,622	93	70	77.25	75.92	73.00	4.60	2.15	4.15	3.16
B	10	230	170	9.6	13,766	102	74	86.00	87.83	84.17	7.80	4.02	8.38	7.22
C	18	70	156	-5.8	13,766	107	71	86.75	84.83	82.08	4.60	2.33	4.32	3.93
	19	240	242	-5.9	13,766	103	86	90.25	89.00	86.67	7.50	6.44	7.19	6.61
D	24	300	184	-1.2	13,766	96	75	84.00	86.75	83.00	11.20	6.22	12.72	10.65
E	38	180	54	0.1	8879	91	44	49.33	49.17	46.50	9.10	3.19	8.92	5.96
	39	80	56	1.2	8879	82	45	48.83	48.50	45.83	3.50	1.71	3.34	2.10
F	41	90	134	-0.6	8879	78	62	56.92	56.00	54.75	2.70	2.54	2.73	2.77
	42	80	60	-1	8879	76	45	54.58	54.25	52.58	3.40	1.81	3.34	3.07
G	45	50	69	0	8879	68	48	55.17	53.50	52.25	1.80	1.21	1.66	1.56
	46	90	97	-0.4	8879	66	58	58.92	56.42	55.42	2.50	2.39	2.20	2.08
H	47	250	63	0	8879	73	50	56.33	53.92	53.92	5.80	4.42	5.27	5.27
I	48	260	44	0.5	8879	75	43	50.00	48.42	47.17	7.30	4.10	6.58	6.00
Total											**80.4**	**45.5**	**78.2**	**66.8**

F.7 Benefit calculation example

Figure F.2 An example of benefit calculations, urban fixed ISA mean-speed benefits[a]

Worksheet 6 - Accident cost savings

	Movement category	All movements	Vehicle involvement	All vehicles
1	Do-minimum mean speed	45.8	Road category	All roads
	Posted speed limit	50	Traffic growth rate	2.00%
2	Option mean speed	44.9		

	Do-minimum	Severity: Fatal	Serious	Minor	Non-injury
3	Number of years of typical accident rate records	5			
4	Number of reported accidents over period	356	4534	25403	
5	Fatal/serious severity ratio (tables A6.19(a) to (c))	0.08	0.92	1.0	1.0
6	Number of reported accidents adjusted by severity **(4)** x **(5)**	391.2	4498.8	25403	
7	Accidents per year = **(6)/(3)**	78.24	899.76	5080.60	
8	Adjustment factor for accident trend (table A6.1(a))	0.9			
9	Adjusted accidents per year = **(7)** x **(8)**	70.416	809.784	4572.540	
10	Under-reporting factors (tables A6.20(a) to (b))	1	1.5	2.75	7
11	Total estimated accidents per year = **(9)** x **(10)**	70.416	1214.676	12574.485	
12	Accident cost, 100km/h limit (tables A6.21(e) to (h))	3,800,000	405,000	24,000	2,400
13	Accident cost, 50km/h limit (tables A6.21(a) to (d))	3,350,000	360,000	21,000	2,100
14	Mean speed adjustment = (**(1)** - 50)/50	-0.084			
15	Cost per accident = **(13)** + **(14)** x [**(12)** - **(13)**]	3,312,200	356,220	20,748	2,075
16	Accident cost per year = **(11)** x **(15)**	233,231,875	432,691,885	######	
17	Total cost of accidents per year (sum of columns in row **(16)** fatal + serious + minor + non-injury)	$926,819,175			
	Option				
18	Percentage accident reduction	22	22	7	0
19	Percentage of accidents 'remaining' [100 - **(18)**]	78	78	93	100
20	Predicted accidents per year **(11)** x **(19)**	54.924	947.447	11694.271	
21	Accident cost, 100km/h limit (tables A6.21(e) to (h))	3,800,000	405,000	24,000	2,400
22	Accident cost, 50km/h limit (tables A6.21(a) to (d))	3,350,000	360,000	21,000	2,100
23	Mean speed adjustment = (**(2)** - 50)/50	-0.102			
24	Cost per accident = **(22)** + **(23)** x [**(21)** - **(22)**]	3,304,100	355,410	20,694	2,069
25	Accident cost per year = **(20)** x **(24)**	181,475,974	336,732,238	######	
26	Total cost of accidents per year (sum of columns in row **(25)** fatal + serious + minor + non-injury	$760,209,457			
27	Annual accident cost savings = **(17)** - **(26)**	$166,609,717			
28	PV accident cost savings = **(27)** x DF^{AC}	$1,601,354,523			
	Transfer PV of accident cost savings, **E** for the preferred option to **E** on worksheet 1				

a) These benefit calculations assumed a 2% traffic growth over New Zealand, which is the average of the default traffic growth rates reported, by region and major city, and by rural and urban road type, rounded to the nearest ½% in table A2.5 of the Economic Evaluation Manual (NZTA 2010). In addition, the factors applied were for all movements and all vehicles; and the under-reporting factors applied for rural roads were those for 80km/h and 100km/h speed limits (excluding motorways).

Figure F.3 An example of cost calculations, including all costs considered, as well as the cost for developing variable ISA

Worksheet 3 - Cost of the option(s)

1 PV of estimated cost of proposed work (as per attached estimate sheet)

$ 560540000 x 0.93 = $ 521302200 **(a)**

2 PV of maintenance in year 1 168040000 **(b)**

3 PV of annual maintenance and inspection costs following the work

(years 2 to 30 inclusive) $ 168060000 x 10.74 = $ 1804964400 **(c)**

4 PV of periodic maintenance costs

Base date 1st July in the year 2014/15

Year	Type of maintenance	Amount $	SPPWF	Present Value
2019/20	Purchase new ISA device	560000000	0.63	352894991
2024/25	Purchase new ISA device	560000000	0.43	240174401
2029/30	Purchase new ISA device	560000000	0.29	163458662
2034/35	Purchase new ISA device	560000000	0.20	111247219
2039/40	Purchase new ISA device	560000000	0.14	75712988

Sum of PV of periodic maintenance costs = $ 943488261 **(d)**

5 PV cost of additional annual maintenance

$ x 10.74 = $ 0 **(e)**

6 PV of total costs of optioi

PV total costs **(a)** + **(b)** + **(c)** + **(d)** + **(e)** = $ 3437794861 **B**

Transfer the PV total costs for the preferred option **B**, to **B** on worksheet 1.

F.8 Cost breakdown for a possible speed limit management system solution

Table F.11 Cost breakdown for a possible speed limit management system solution

Item no.	Description	Assumptions and tasks	Cost
A	The creation of a national spatial database, with speed limits including variable speed limits and other related information such as Gazette notices, to be recorded against roads (about 94,000km).	Amalgamation of RCA spatial and non-spatial data into a common dataset, including relational database for Gazette and textual information. Different levels of complexity and data conversion required to conform to new common format for different RCAs. Other tasks: a) Analysis and workshop of study already conducted to design new database schema. b) Define business processes for maintenance and workflow with the new system. c) System design and architecture based on maintenance requirements. d) Design and implement RCA spatial data updates.	$91,000
B	The migration of existing data to this database, assuming that GPS coordinates for all speed zone boundaries will be provided.	a) Load all RCA data into common format, including testing. b) Test and validate loaded data with RCA or RCA representative.	$8000
C	A system for managing road centreline changes – either by changing them manually or allowing for direct import of changes from, say, a GIS-based system.	a) Data validation between the common format RCA is performed by exporting the common format and comparison made by the RCA. b) RCA data is in the same projection as the common RCA format. c) There are operators available to maintain the common RCA format. d) Requires a work flow to be defined for operators to perform task.	$10,000
D	A system for managing future changes to speed limits. This would probably involve each RCA having access to the roads they manage and being able to make changes to the speed limits.	a) Assumption, once all RCA have been amalgamated into a common format, that each RCA will update their own spatial data by taking a copy of the common format for their jurisdiction. b) Assumes two forms of updating: i) batch spatial update ii) spatial editing of textual speed limits; ie no spatial edits functionality are available. c) Assume supporting technology is selected that allows editing over the web; eg ArcGIS Server. Note 1: If spatial editing is required, the assumption is we would only use the editing functionality that exists in ArcGIS Server out-of-the-box. Note 2: Business workflows are also required if spatial web editing is to validate and approve for release/publication.	$8000
E	A system for the public to notify the NZTA of errors/issues.	a) A simple textual feedback/notification of errors and issues. b) Creation of public feedback forms. c) Operators and business processes already exist to monitor and maintain feedback forms.	$5000

Item no.	Description	Assumptions and tasks	Cost
F	A system for exporting the data to RAMM.	a) Both the RAMM system and the proposed system use the same software/application platform. b) Script the export or database replication.	$8000
G	A system for making the information publically viewable (ie publish to the web) as well as a system for it to be downloadable from the internet for commercial map providers and onto ISA devices.	a) Assume different forms of web services: i) Map configuration and publishing of map services = 10 days [assume spatial software already installed, assume client will provide standard symbology, performance testing, map cache creation] ii) Web (non-spatial) services = 5 days [assume using existing infrastructure] iii) Downloaded, predefined maps – assume existing map creation work procedure exists for standard map output. This process would be automated from the common format = 2 days. b) IMPORTANT NOTE 1: There is no provision to create a web application for viewing of map services in this project's scope. This is because it would be best for RAMM to host the viewing of map services (ie after the data export). c) IMPORTANT NOTE 2: If a web application is required, this requires a lot of additional information, such as infrastructure, look-and-feel, themes, presentation, support, redundancy, additional reference data, displayed as base maps, etc.	$29,000
H	An option for some sort of workflow where the RCA would make a proposed change and then be able to have it automatically sent (together with any required documentation) to the agencies that are required to approve the change, and have the ability for them to approve the change.	a) Define workflow of various components and streamline data exchange.	$9000
Total			**$168,000**

F.9 Appendix F references

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Glossary

Advisory ISA: A type of ISA that provides the driver with feedback about local speed limits without exerting any control over the vehicle.

Advisory zone: Speed zones that are not the legal posted limit; eg recommended speeds on tight corners.

Dynamic ISA: A type of ISA that, in addition to the fixed and variable functionality, includes the ability for speed limits to vary both temporarily and spatially; ie lower speeds may be implemented due to weather conditions, in response to incidents or congestion, or around schools when students are arriving or leaving.

Fixed ISA: A type of advisory ISA system that displays local speed limits and reminds the driver of changes to the speed limit. It also alerts the driver when they are travelling faster than the speed limit (providing different auditory feedback at both 3km/h and 8km/h over the limit).

Intelligent Speed Adaptation (ISA): A system that constantly monitors vehicle speed in comparison to the local speed limit, providing the driver with feedback.

Mandatory ISA: A type of ISA that limits the speed of the vehicle based on the local speed limit. Also known as 'Intelligent Governor'.

Out-of-context curve: The degree to which a curve is out of context with its surrounding environment is related to the difference between the curve speed and the curve approach speed. Curve radius is an indicator for whether a curve is likely to be out of context, and as such, Out-of-context curves are identified in the NZTA's Road Asset Management and Maintenance system (RAMM) as those with a curve radius of less than 400m.

Route: The driving route used in the experimental trial undertaken as part of this research. Additional detail is available in section 8.2.1.

Speed zone: The legal posted speed limit in the zone or area where it applies.

Variable ISA: A type of advisory ISA. This system is the same as the fixed ISA system, with the addition of providing the driver with feedback about advisory speed zones. The system alerts the driver of speed limit and advisory limit changes and provides auditory feedback when the vehicle exceeds these (providing different auditory cues at 15km/h and 30km/h over the advisory limit).

Voluntary ISA: A type of ISA that allows the driver to enable and disable the ISA control by the vehicle of the maximum speed. Also known as 'Driver Select' ISA.