Considering a cost–benefit analysis framework for intelligent transport systems

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An important note for the reader

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Introduction

The purpose of this research was to consider a cost-benefit analysis framework for public policy development that takes account of the potentially distinctive costs and benefits of intelligent transport systems (ITS) projects.

Since ITS projects involve new technology it is likely that some of the benefits are not identified and quantified by the current New Zealand transport project evaluation procedures contained in the *Economic evaluation manual* (EEM). The objective of this research was therefore to explore the range of common ITS project benefits and assess if they can be evaluated using the existing EEM procedures.

To satisfy this objective, a methodology was developed to evaluate the value of the ITS project components where the EEM procedures do not satisfactorily capture ITS benefits. Such a methodology would enable a comparison of the non-monetised aspects with the monetised outputs of ITS projects.

Literature review

As part of this research we undertook an extensive review of New Zealand and overseas literature on a range of topics relevant to the evaluation of ITS projects. We focused on the methodologies used to evaluate ITS applications and the reported benefits of the various ITS functionalities. The literature search was conducted using the NZ Transport Agency (the Transport Agency) research reports database, international ITS databases (predominantly British, American and Australian) and AECOM international reports.

The purpose of the literature review was to identify:

- the types of benefits and costs, and the range of values associated with ITS projects in the multimodal road transport environment in New Zealand and overseas
- the methodologies for assessing the benefits of ITS projects that have been developed, proposed or applied.

There is a general agreement expressed in the published material that ITS can bring substantial benefits. Nevertheless one has to be aware of possible pitfalls or overstating the benefits. For instance when a significant number of drivers see a variable message sign (VMS) and react to it by selecting the same alternative route, this route can get congested and cause delays greater than the delay for vehicles remaining on the original route.

At times evaluation can claim unsubstantiated benefits. For example the benefits to motorway traffic resulting from ramp metering may be offset by long delays from vehicles queueing on the ramps. There is also a potentially sensitive issue of the invasion of privacy. The route, the origin and destination of the motorist's trip are proprietary information, but the audio recording along with the video image might belong to the domain of private information.

The reported benefits of improved ability to make informed choices by travellers having access to advanced traveller information systems include up to 70% reduction in travel delay caused by incidents, up to 16% improvement in public transport travel time reliability, up to 20% travel time saving due to informative VMS messages, up to 40% reduction in the duration of incidents, and up to 50% reduction in secondary crashes at incident sites. Application of red-light cameras resulted in reductions of up to 60% violations and 50% of crashes.

The review found many examples of literature providing information on the benefits of ITS both qualitative and quantitative. However, very little material was found on specific methodologies comparing the value of monetised user benefits from ITS elements, such as real-time information display at bus stops, with the monetised benefits from infrastructure improvements, such as travel time saving.

Review of the *Economic evaluation manual*

The group of ITS functionalities which physically enhance the performance of the transport network can be adequately assessed by the procedures contained in the EEM. We have identified the following ITS applications which can be assessed using the manual: adaptive and advanced signal control and arterial management, ramp signalisation (metering), early detection and management of incidents, traffic signal pre-emption for buses, parking management systems, automatic vehicle location and computer aided dispatching, speed enforcement and red-light cameras.

It should be noted that at times some assumptions have to be made to do these assessments, for instance the duration of the incident, or the amount of traffic that would divert to other routes.

The second group of ITS functionalities does not physically alter the transport network but provides information to the traveller to help them to select the most appropriate route for their trip or the best time to start the trip or the most appropriate mode.

There are a few aspects of traveller information that make the uptake/use of traveller information difficult to assess/evaluate using the EEM. The first is whether the traveller receives the information, the second is if they act on the received information, and the third is whether they derive the expected benefits. None of these can be easily assessed using the procedures contained in the EEM. The EEM notes there are various techniques that allow economic values to be assigned to benefits, eg willingness to pay, avoidance or mitigation costs and where benefits that do not have monetary values in the manual are likely to be significant, it may be desirable to undertake such an analysis. The manual states that where no monetary value is available, the benefits should be described and where possible quantified, and also reported as an input into the Transport Agency’s funding allocation process.

Existing ITS evaluation methodology

Very little material on the topic of attaching monetised values to customer satisfaction arising from traveller information is evident in the international literature. Most of the studies reviewed revealed that evaluations have often focused on traveller satisfaction surveys, or the technology used to provide them. A commonly expressed opinion in the studies is that the evaluation of ITS projects is complicated by the presence of the unique variables. In addition the studies often state that ITS benefits such as user satisfaction and comfort, improved availability or quality of information are difficult to quantify, although the EEM does provide values for driver and passenger comfort in cars and on public transport and willingness to pay has been used to value real-time information. Nevertheless, we consider the case for the presence of unique variables associated with ITS benefits needs further research before it can be accepted. If one asks the question ‘why is the customer satisfied?’, one may find the benefits that contributed to the satisfaction are already counted, and hence user satisfaction would be double counting benefits. It needs to be proven that double counting will not occur.

It is important that the evaluation of the technology concerned includes rigorous sensitivity testing and does not imply false precision to the estimated impacts. The ITS evaluation methodology must allow comparison of ITS projects with non-ITS projects. The EEM covers this adequately.

Conclusions

A review of the international literature brought information about the benefits of the ITS applications as well as their potential drawbacks, and the methodologies used to assess the benefits of the aspects which cannot be quantified, such as provision of information to travellers and transport authorities. The literature review found many examples of literature providing information on the benefits of ITS both qualitative and quantitative. However, very little material was found on specific methodologies comparing the value of monetised user benefits from ITS elements, such as real-time information display at bus stops, with the monetised benefits from infrastructure improvements, such as travel time saving.

A review of the EEM identified procedures that can be used in the evaluation of ITS applications. However, there are ITS aspects which cannot be satisfactorily assessed by the EEM procedures and further work into these areas is recommended.

In conclusion, the international literature review and review of the EEM have confirmed there are major gaps in existing ITS evaluation methodologies and further work into these areas is recommended.

Recommendations for further applied research on specific topics and work to fill this gap are given in the report.

Furthermore, pure research is recommended to address the gap in the economic theory underpinning ITS benefits, for example, whether willingness to pay or willingness to accept is the appropriate methodology for assessing ITS benefits.

Abstract

The purpose of this research was to consider a cost–benefit analysis framework for public policy development that takes account of the potentially distinctive costs and benefits of intelligent transport systems (ITS) projects.

Since ITS projects involve new technology it is likely that some of the benefits are not identified and quantified by the current New Zealand transport project evaluation procedures contained in the *Economic evaluation manual* (EEM). The objective of this research was therefore to explore the full range of common ITS project benefits and assess if they can be evaluated using the existing EEM procedures.

1 Introduction

1.1 Purpose of this research

The purpose of this research was to consider a cost–benefit analysis framework for public policy development that takes account of the potentially distinctive costs and benefits of intelligent transport systems (ITS) projects.

Since ITS involve new technology it is likely that some of the benefits of ITS are not identified and quantified by the current New Zealand transport project evaluation procedures contained in the *Economic evaluation manual* (EEM) (NZ Transport Agency 2013). The objective of this research was therefore to explore the full range of common ITS project benefits and assess if they can be evaluated using the existing EEM procedures.

1.2 Concept of the ITS functionality for the purpose of this research

In its position statement on ITS the NZ Transport Agency (2014) provides the following definition:

> *Intelligent transport systems apply information and communication technologies that support and optimise all modes of transport by cost-effectively improving how they work, both individually and in co-operation with each other.*

The key message of this definition is that through the application of information and communication technologies to all transport modes an optimised transport system solution may be achieved leading to cost-effective improvements of the system. This emphasises the novelty of their reliance on information and communication to address transport problems. Such a concept does not appear in conventional transport projects, which rely mainly on the physical improvements of the transport system producing measurable travel time, safety and/or vehicle operating cost savings.

ITS can be seen as a complete system where technology is the means towards achievement of distinct social, economic and policy ends. This rationale has inspired promotion of ITS as the use of technology for 'smart' system management. One large analytical advantage of this concept is that mere technical advancement is not accepted as a good in and of itself but only a good if it improves social welfare in some way (Gordon 2013).

The following definition is used by the ITS Policy Committee of the International Road Federation (IRF) (IRF 2015):

> *Intelligent Transport Systems (ITS) apply Information and Communication Technologies (ICT) that support and optimise all modes of transport by cost-effectively improving how they work, both individually and in cooperation with each other. This concept of ITS is made up of broad fields of application with numerous stakeholders involved:*
>
> - *Infrastructure related ITS: applications that focus on availability and quality of transport infrastructure and that can be used to intervene in traffic capacity, to enable paying for road use, to detect incidents or hazardous weather conditions, among others.*
> - *Vehicle related ITS: applications that are put in the car to support in the driver task and/or to assist in management of a fleet of vehicles.*

- *User related ITS: applications that focus on convenience and efficiency for travellers, reducing barriers to switch transport modes and provide real-time and forecast information*
- *Industry related ITS: applications aimed at reducing costs and/or maximizing profits in the operation of transport.*
- *Vehicle-to-infrastructure/vehicle-to-vehicle related ITS: so called cooperative systems foresee the real-time interaction among vehicles and between vehicles and the road infrastructure, in order to enhance primarily traffic safety.*
- *ITS back-office systems: applications aimed at processing collected data, storing data for historic analysis, cross-application processing and system integration, providing the base for tailored, real time information flows to road managers and users.*

ITS technologies are tools that vehicle owners, funders and policy makers can use to make transport systems across all modes of transport safer, more efficient, more resilient and more sustainable. The following definition of ITS has been proposed by the Ministry of Transport (MoT 2014b). This definition was adopted for the purpose of this research:

> *Intelligent Transport Systems (ITS) are those in which information, data processing, communication and sensor technologies are applied to vehicles (including trains, aircraft and ships), infrastructure, operating and management systems, to provide benefits for transport service users.*

There is little agreement internationally on which components of ITS are more beneficial than others. According to Hu et al (2002) for example, USA decision makers favour the freeway mobility and use the following priority list as a guide:

1. Freeway management
2. Incident management
3. Arterial management
4. Emergency management
5. Transit management
6. Electronic toll collection
7. Electronic fare payment
8. Highway-rail intersections
9. Regional intermodal traveller information.

One of the leading ITS exponents internationally is South Korea. As part of the country's ITS master plan for 2008 to 2020 it invests about US$230 million annually in ITS deployment. It has established four initial 'ITS model cities', where the ITS infrastructure is implemented according to this level of priority:

1. Adaptive traffic signal control
2. Real-time traffic information
3. Public transport management
4. Speed violation enforcements

Subsequently 29 cities adopted this approach (Ezell 2010). In comparison with the USA the Korean model is modest, but by emphasising the priorities of the urban non-motorway travel, it is closer to New Zealand interests.

In his research conducted earlier for the Transport Agency, James (2006) concluded that the best-aligned ITS systems were those that addressed the following four key elements of demand management:

1. Improving ability to make informed choices (advanced traveller information systems)
2. Control and management of traffic flow (adaptive signal control/ramp metering/parking systems)
3. Early detection and management of incidents (detection and monitoring systems)
4. Influencing travel choice through direct means (congestion charging).

Based on the above, for this research we have adopted the following functionalities as the most important for ITS applications in New Zealand:

1. Improving ability to make informed choices (advanced traveller information systems)
2. Control and management of traffic flow (adaptive signal control/ramp metering/incident detection and management/parking systems)
3. Public transport management
4. Speed and red-light violation enforcements.

Ability to make informed choices saves travel time and enhances confidence in the transport system. Management of traffic flow maximises the capacity of the road network. Improving public transport is a key focus of the government and city transport policies. Law enforcement on the roads is critical to safe traffic operations.

1.3 Synergy with other New Zealand research

1.3.1 Neil Douglas

Research into the benefits of public transport service enhancements has been carried out by Neil Douglas (in press) and this may in time lead to such improvements in the EEM. However, ITS was not the focus of this research and it is unlikely to provide comprehensive information about ITS benefits.

The study assessed the trade-off between price and quality for bus and train users in Auckland, Christchurch and Wellington. A survey of 12,557 bus and rail passengers was carried out between November 2012 and May 2013 on 1,082 different bus and train services.

For real-time information at bus stops, the overall passenger satisfaction rating was found to range from a low of 46% when no facilities were provided to 75% where shelter, seating, real-time information and a timetable was provided. When valued, the willingness to pay from providing a shelter was worth 9% of fare, seating 3%, real-time information 3% and a timetable 2%. In terms of importance, a shelter was found to explain 51% of the overall bus stop rating, real-time information 20%, seating 17% and a timetable 12%.

1.3.2 Ian Wallis and Bevan Wilmshurst

Ian Wallis and Bevan Wilmshurst are currently conducting a study of the benefits of network operation activities. We have discussed areas of potential overlap between their and our research and concluded there is no overlap.

Part 1 of their research, which they are currently undertaking, deals with a broad evaluation framework of network operations. Some ITS activities are included in this broad framework; however, our research deals with specific evaluation methodologies.

1.4 Multimodal ITS

A multimodal transport system is where people and goods have the ability to choose different modes of travel. Such a system can be enhanced by good information provision allowing more informed choices.

A trip by an individual can also be multimodal with different parts of the trip being undertaken by different modes (eg walk or cycle or drive to a station, take public transport, then walk or cycle or drive to destination). Such a trip can also be enhanced by good information.

Enhancement and better use of modes in a multimodal transport system can make the system more sustainable in terms of cost-effectiveness, efficiency and environmental friendliness, as well as fulfil society's mobility and transport needs. To achieve effective use of all available modes by people and goods, a proper physical and information infrastructure, advanced transport systems and operations, as well as ad hoc and seamless services are required (Mesqui 2015).

Cars, buses, trucks, trains, ferries, ships, planes, roadside electronic infrastructure and portable smart devices such as smartphones will communicate with each other. They share critical information on safety, mobility, freight and environmental aspects over communications links. Such a system of 'interconnectivity' of human, vehicle and infrastructure provides a massive transportation database, from which innovative and transformative applications are built to allow smarter, more enjoyable and significantly safer travel, irrespective of the mode used.

Travellers benefit from real-time multimodal information, leading to more efficient and eco-friendly choices regarding travel routes and modal choices. For instance, informed travellers may decide to avoid congestion by taking alternate modes (such as walking, biking, or public transport) or by rescheduling their trip time or route (US DoT 2015d).

Multimodal travel is very complex in its nature, but can be aided by journey application planners. These tools assist travellers in planning their journeys from point X to Y providing information on the different types of transport to take, as well as schedules and fares.

Ellizer (2014) stated that the benefits of multimodal ITS include:

- *Travellers benefit from real-time, multimodal information that leads to more efficient and eco-friendly choices regarding travel routes and modal choices.*
- *Transportation agencies benefit by being able to see and respond dynamically to manage conditions on the transportation network across all of the modes.*
- *Traffic operators benefit from having tools to manage the multi-modal system more efficiently, saving fuel, and reducing environmental impact.*
- *Freight operators benefit from efficient systems that facilitate synchronisation and co-ordination shipments across modes – road, rail, sea and air freight.*

As mentioned above ITS are not limited to land-based vehicle transport, but are being developed for different transport modes and for interaction between them (including interchange hubs or inter-modal freight depots). International and local examples of multimodal ITS development in other modes of transport are discussed below.

1.4.1 Air

In Europe, the Single European Sky ATM Research (SESAR) framework is being jointly developed by the European Union and a consortium of national air traffic control organisations and suppliers to create a new generation air traffic management system capable of ensuring the safety and free flow of air transport worldwide over the next 30 years. SESAR is the technological pillar of the Single European Sky (European Commission 2015).

In New Zealand, the project New Southern Sky was launched in 2014. Its purpose is the modernisation of airspace and air navigation that will result in improved efficiency of air traffic movements, improved accuracy of navigation, reduced reliance on ground-based systems and improved communications. An increase in the availability of information will also enable more effective decision making. Together, these changes will mean lower operating costs and improved aviation safety (New Southern Sky 2015).

1.4.2 Water

European inland waterways introduced river information services (RIS) to manage waterway utilisation and the transport of freight. The data gathered via the transponders on vessels and the antennae on the ground will be collected and centralized at the RIS centre and used to create new services based on the actual and precise location of vessels in the river and canal network (eg improved calamity abatement, better lock management, improved navigability instruments) (European TEN-T 2011).

The European Maritime Safety Agency has introduced SafeSeaNet, a vessel traffic monitoring and information systems and is progressing towards an automatic identification system and long-range identification and tracking (European Commission 2015).

Australia is continuing development of the world class ship reporting system and integration of this system with the vessel traffic services system for sea ports (Queensland Government 2005).

1.4.3 Rail

The rail industry internationally has historically been an early adopter of technology to provide signalling systems to facilitate the efficient and safe movement of passengers and freight across rail systems. The more recent adoption of computer systems has enabled management and tracking of freight consignments between shippers and customers. However rail signalling and communications systems and the underlying technologies evolved independently to meet the requirements of individual rail organisation’s needs with little thought to potential problems when trains crossed international boundaries or between different rail systems.

This resulted in inefficiencies and increasingly lack of competiveness as road transport improved. Therefore in the early 1990s, the European Union and railway industry developed the European Rail Traffic Management System (ERTMS) and the underlying European Train Control System (ETCS) technology that was designed to improve the operation of rail services across national boundaries and to enhance the international competiveness of the European rail industry suppliers. The ETCS system has integrated command and control functionality with a new radio system for voice and data communication, and is a multi-vendor technology platform (ERTMS 2014).

While interoperability across borders is not an issue for rail in New Zealand, the effect of the increasing globalisation of rail technologies is providing benefits for KiwiRail and the other New Zealand rail organisations. ETCS technology has been installed in Auckland as part of the recent electrification project to provide an automatic train protection system to prevent trains from passing red signals and exceeding speed limits (NZ Transport Agency 2013b).

In New Zealand, in the mid 2000's, KiwiRail's predecessor organisation, ONTRACK, in conjunction with a New Zealand company, Xworks, developed the KUPE GPS-based train location reporting system to provide an economical means of knowing the location of trains, particularly on low traffic density routes, and to provide enhance protection for track workers (IPENZ 2007).

An emerging area of multi-modal ITS is the research undertaken in Victoria in recent years to improve rail level crossing safety by using dedicated short range communications technology to improve railway level crossing safety by providing a 'radio break in system' that alerts vehicle drivers to the approach of trains at level crossings (Public Transport Victoria 2012).

1.5 Future directions of ITS

1.5.1 New Zealand

The Government's *ITS action plan 2014–2018:Transport in the digital age* (MoT 2014b) indicates government's awareness of the expected paradigm change in ITS applications and technologies in the near future:

> *Intelligent transport systems – which use sensors, computing and communication technologies – are becoming integral to transport in New Zealand and around the world. They play a major role in making travel safer and more efficient. Intelligent transport systems technologies are new and evolving tools that will help the government achieve its transport objectives.*

The action plan was drafted by the Ministry of Transport in cooperation with other government departments and transport agencies. It takes a multimodal, multi-agency approach to the introduction of ITS in New Zealand over the next four years. It contains 42 actions ranging from establishing an ITS leadership forum, a government ITS technology working group and issuing policy about the role of ITS in contributing to the *Government policy statement on land transport* (GPS) (MoT 2015), to allocating radio spectrum for ITS applications, investigating the merits of electronic road user charging and reviewing legislation associated with testing driverless cars.

The government reasons that these actions will ensure ITS technologies can contribute to the government's objectives for all modes of New Zealand's transport system. The action plan does not discuss in any detail investment assessments or decisions. These are made by the responsible parties, for example Airways New Zealand, Land Information New Zealand, the Transport Agency and the private sector.

The areas where the government perceives major impacts of ITS are active network management, information provided to travellers, advanced driver assistance systems, fully autonomous vehicles, charging and payment technologies, and future network planning.

The Transport Agency published the *NZ Transport Agency position statement on intelligent transport systems – responding to the opportunities* (NZ Transport Agency 2014c), where it set out the opportunities presented by ITS.

According to the document, ITS offer the New Zealand transport sector opportunities to take performance to the next level – enabling dramatic improvements in:

- the way data about traffic flows and the state of the network is gathered and used
- the amount and quality of the data

- the ability to communicate with travellers
- the ability to resolve operational issues in the transport network
- the ability to protect people from their and others' mistakes.

The focus of the document is how ITS can contribute to each of the 12 medium-term goals specified in the Transport Agency's (2013) 2013–16 *Statement of intent*, together with an assessment of the steps that the Transport Agency needs to take to achieve the goals.

The Transport Agency also identified five ITS-related investment areas that it believes would make the greatest contribution to achieving its medium-term objectives:

1. Integrated networks for customers
2. Smarter transport choices
3. Safer speeds and safer vehicles
4. Improved freight supply chain efficiency
5. Innovative payment, prices and compliance approaches.

The document mentions that specific intelligent transport system benefits will be influenced by evolving technologies and market demands. The Transport Agency will continually monitor the global transport sector to ensure that its ITS efforts and investment practices are maximising returns for New Zealand.

In a recent New Zealand Institute of Economic Research (NZIER) report (Allison 2014) two emerging technologies were investigated – driverless vehicles (smart cars) and electric cars. These technologies combined, ie smart cars powered by electric motors, were predicted to be most disruptive technologies of the 21st century.

The report claims that these technologies will change the demand for motoring and affect the pay-as-you–go road user revenue base, as well as challenging the use of public transport, as car travel will become cheaper. This, however, will be achieved with a dramatic reduction in crashes and a reduction of road congestion. The road capacity may increase by up to 250% without additional investment in the road infrastructure.

Allison (2014) concludes that accelerating the adoption of the new technologies may have a bigger payback than spending on road and rail infrastructure. This view is consistent with an earlier study by Parker et al (2009), who postulated the net benefit of the widespread market uptake of electric vehicles in New Zealand to be in the order of $8.5 billion.

An important aspect of the recent trends in ITS evaluations is that road agencies are increasingly turning to simulation studies to evaluate the wider benefits of ITS, particularly when testing the feasibility of new technologies. This can be carried out by two methods:

1. An offline evaluation using different scenarios and running a large number of experiments, for example, how ramp metering might work on a certain new freeway, or
2. Through using more advanced emerging trends which include the use of online real-time simulations to evaluate the effectiveness and benefits of incident management strategies.

1.5.2 Overseas

In December 2008, the European Commission adopted an action plan for the deployment of ITS for road transport and its interfaces with other modes (European Commission 2013). The aim of this action plan is to accelerate and coordinate the deployment of ITS applications in the European Union.

In December 2014, the US Department of Transportation (USDOT) released its *ITS strategic plan 2015–2019*, which outlines the direction and goals of the USDOT's ITS programme and provides a framework around which the ITS Joint Program Office and other department agencies will conduct research, development, and adoption activities to achieve them. The two main technological drivers are to realise connected vehicle implementation and to advance automation. The plan has proposed the vision to 'Transform the way society moves' (US DOT 2015e).

ITS Canada recently presented its *2015–2019 strategic plan*. This plan reflects the rapidly evolving nature of the ITS landscape and the realities of operating a member-based organisation in challenging economic times. The document acknowledges that significant changes in the traditional ITS sectors (traffic, transit, ports and borders) are anticipated as the result of impending technological changes from connected and automated vehicles (ITS Society of Canada 2014).

In March 2012, ITS Australia issued its *National intelligent transport systems industry strategy*. It encompasses multi model land transport and a five year timeframe from 2012 to 2017. The strategy promotes three core pillars of safety, mobility and the environment (ITS Australia 2012).

In May 2010, the government of Japan released its 'new IT strategy' which described the short-term targets up to FY2013 and the long-term ones up to FY2020. The strategy consists of three main points:

1 Realisation of E-government service

2 Re-bonding local communities

3 Creation of new markets and international expansion.

ITS is embedded in points 2) and 3) by introducing and deploying the safety driving support systems to revitalise local communities, and by setting the target to halve the traffic congestion on main roads in Japan by FY2020 compared with those of FY2010 by applying ITS technologies. 'Green mobility' is also promoted here, combining the smart grid technologies with the transport systems such as electric vehicles (ITS Japan 2010)

In addition the Public-Private ITS Initiatives & Roadmap was released in Japan in March 2014. It aims to realise the world's safest, most environmentally friendly and most economical road traffic society (SAEJ 2014).

Numerous overseas initiatives have a much broader reach than those currently being considered in New Zealand. The following summarises the initiatives that are deemed important background for this study:

1.5.2.1 Autonomous vehicles

Fully automated navigation systems will enable roads to be populated by driverless cars, which would affect the design and operation of highways, but provide safety and environmental benefits (ARUP 2014). Potential benefits of autonomous vehicles are substantial. For example research by Morgan Stanley (Allison 2014) indicated that the widespread adoption of driverless technology in the United States would be worth around USD$1.3 trillion annually. This is equivalent to around 7% of the United States 2013 GDP.

These savings come from the reduction of fuel consumption (US$158 billion), reductions in crash costs (USD$488 billion), increased productivity (US$507 billion) and congestion cost savings (USD$149 billion).

1.5.2.2 Electric cars

Developments in the science of materials will improve the performance of batteries and increase the storage of electricity. This will encourage the use of electric vehicles in the road networks, with anticipation that these vehicles will become commonplace (ARUP 2014).

Electric vehicles uptake in Europe will accelerate with the assistance of an open access fast charging corridor along major motorways. The project funded by the Trans-European Transport Networks (TEN-T) aims at installing a total of 155 charger by the end of 2015 (European TEN-T 2014).

1.5.2.3 Passenger car connectivity

The European Automobile Manufacturers' Association (ACEA) has brought together key industry stakeholders and policy makers to review the opportunities related to passenger car connectivity. Automotive connectivity technologies would revolutionise personal mobility (ACEA 2014).

1.5.2.4 Advanced road surface materials

A recent study by ARUP (2014) investigates self-healing concrete pavements (which contain bacteria to fill cracks when concrete gets damaged), replacing road surface with advanced solar panels that would generate power for charging electric cars in motion, and glow-in-the-dark road surface materials to display messages to motorists at night.

1.5.2.5 Changing pattern of car ownership

Patterns of car ownership are expected to change with commuters purchasing access to a vehicle for short periods rather than purchasing the vehicle itself (ARUP 2014).

1.5.2.6 Intelligent mobility

The iMobility Forum is a broad consortium of European stakeholders who have an interest in ITS, services and works to develop resource-efficient, clean and safe transport systems. The three-year iMobility Support project assists with stakeholders networking, product deployment and communications (ERTICO-ITS 2013).

2 Literature review

2.1 Introduction

As part of this research we undertook an extensive review of New Zealand and overseas literature on a range of topics relevant to the evaluation of ITS projects. We focused on the methodologies used to evaluate ITS applications and the reported benefits of the various ITS functionalities. Although we tried to retrieve mainly the reported results of the post-evaluation studies, there was not enough material available. We therefore had to also use the results of the computer simulation and modelling studies, usually carried out for assessing the potential benefits of the proposed ITS projects.

The literature search was conducted using the Transport Agency research reports database, international ITS databases (especially British, American and Australian), and AECOM international reports. For the search of the relevant material we used the key words ITS evaluation, ITS costs and benefits, incident detection, real-time passenger information systems and route guidance.

The purpose of the literature review was to identify:

- the types and values of benefits and costs associated with ITS projects in the multimodal road transport environment in New Zealand and overseas
- the methodologies for assessing the benefits of ITS projects that have been developed, proposed or applied.

The following section of this report synthesises our findings.

2.2 Structure of the review

The review has two parts – the benefits and costs of the ITS functions, and the methodologies applied to assess the benefits. We have grouped the ITS functions under the following headings: traveller information systems, control and management of traffic flow, incident detection and management, public transport management, parking systems and enforcement.

Traveller information systems were divided into the dissemination of pre-trip travel information and end-route travel information. Control and management of traffic flow was split into adaptive traffic signal control, ramp metering and arterial management systems. Public transport management included real-time passenger information, integrated ticketing, signal pre-emption and automatic vehicle location system. Enforcement included speed enforcement, red-light violation enforcement and detection of unregistered and uninsured vehicles by automatic number plate reading.

The studied ITS functionality is presented in table 2.1.

Table 2.1 Functionality of the different types of ITS

ITS function	Enabling technologies
Pre-trip traveller information	Dedicated websites, telephone dial-in service, radio traffic reports, apps on mobile phones.
En-route traveller information	Variable message signs, highway advisory radio, apps on mobile phones
Control and management of traffic flow	Adaptive and advanced signal control, ramp metering, arterial management systems

ITS function	Enabling technologies
Incident detection and management	Loops, radar, microwave, CCTV or other sensors, central processing unit, highway advisory radio, variable message signs, apps on mobile phones
Public transport management	Real time passenger information display at bus stops, apps on mobile phones, dial-in service, integrated ticketing, signal pre-emption at intersections, automatic vehicle location, computer aided dispatching
Parking systems	Sensors to detect available spaces, variable message signs
Enforcement	Speed camera detection, red-light camera detection, automatic number plate recognition

2.3 New Zealand and overseas practice and experience

2.3.1 Benefits and costs

2.3.1.1 Structure of this section

Initially, we sought to structure this section as shown in the following example:

1 ITS function: eg pre-trip travel information:

  a Websites showing real-time traffic conditions, incidents, weather, etc

    i measured benefits of such applications

    ii simulated benefits of such applications

    iii identified costs of such applications, possibly benefit cost ratios

  b Radio reports providing similar type of information

    i measured benefits of such applications

    ii simulated benefits of such applications

    iii identified costs of such applications, possibly benefit–cost ratios (BCRs).

However, the information retrieved from the literature is not sufficient to meet the requirement of such a format. It is too general, mainly consisting of summary conclusions, such as 'the overall effect of road safety related information is estimated to be an average reduction…'.

Such conclusions do not provide the specifics required for the above structure. They do not provide information on the used technology or whether the results came from observation, measurements, modelling or simulations. Therefore this attempt was unwillingly dismissed and replaced with a more general structure:

1 Pre-trip travel information system:

  a General comments

  b Websites

  c Dial-in telephone services

2 En-route travel information system

   a General comments

   b VMS

3 Control and management of traffic flows

   a Adaptive and advanced signal control

   b Arterial management systems

   c Ramp metering

4 Early detection and management of incidents

5 Public transport management

   a Real-time passenger information

   b Signal pre-emption

   c Automatic vehicle location

6 Parking systems

7 Enforcement

   a Speed enforcement

   b Red-light cameras

   c Registration and insurance compliance.

Each of these subsections contains all the information we had retrieved on the particular technology.

2.3.1.2 NZ Transport Agency's Position Statement on ITS

The NZ Transport Agency's (2014c) *Position statement on intelligent transport systems* divides the ITS benefits into two broad categories: system benefits and traveller benefits. Traveller benefits result from the improvements in the quality of their journey (eg reliability) and safety (eg fewer crashes or reduction in crash severity). System benefits comprise traffic operation benefits (eg maximising network capacity) and investor benefits (eg alternative revenue options). The focus on these benefits drives advances to vehicles, network assets and information.

The position statement also discusses both favourable and unfavourable aspects of ITS. The ITS benefits which are hard to evaluate extend over all initiatives that drive advances to information. This includes provision and sharing information. There are additional factors, both favourable and unfavourable, that need to be considered, namely:

- Reduction in customer effort, which is an existing driver for government. A simplification of combined and shared information not only provides better services but can also get better insights, leading to better investment decisions, more joined up investment, etc.
- Customer satisfaction, which is not a government's focus per se, but would be improved by such actions as better access to information, or faster response to enquiries.
- Increased confidence in accessing services or networks. For example, an app that tells the traveller where car parks are available when they approach their destination also gives them greater confidence at the start of their journey that they will find a park at the end. Or, network management that

guarantees inter-modal, or intra-modal, connections would increase users' confidence in making a journey, over and above the information they received.

- The greater transparency provided by real-time information might increase accountability for service providers, and so might improve services, but not as a direct result of the particular information given to travellers.
- Over-reliance on technology, which is a risk since technologies sometimes fail. The traveller may reach the point when they are unable to make safe decisions without it. This is a human behavioural issue and investigating it is a cost for technology projects dealing with safety concerns.
- Potential invasion of privacy. Traffic surveillance provides better information about the network. This allows better managing of transport and provides opportunities to maximise existing network capacity with consequential benefits. However, there is a point at which data collection about the network and those using it can be perceived as mass surveillance of New Zealand public.

2.3.1.3 Comments on privacy aspects

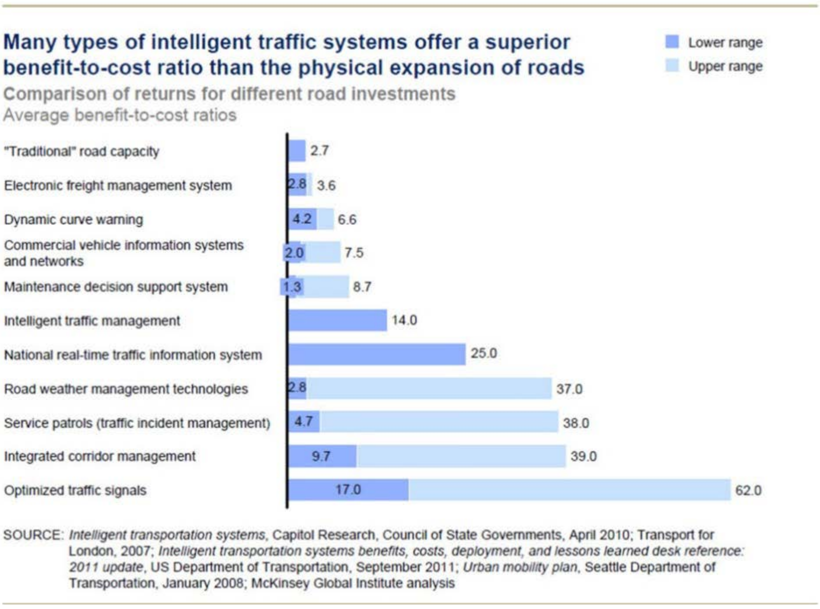
Privacy is undoubtedly a complicated area. The collection and use of data by ITS, including personal and proprietary information, involves potential disbenefits to privacy and security. These disbenefits (or the cost of mitigating them) should be included in cost–benefit analyses, but may be difficult to assess.

The cost of mitigations is probably straightforward – for example the cash option for the Northern Toll road, or the third party processing of location information for electronic road user charges. Privacy concern is an example of a possible disbenefit of ITS projects that is difficult to assess.

2.3.1.4 General perception of ITS benefits

Generally speaking, ITS interventions require less capital outlay than traditional investments in highway capacity and may also have higher BCRs, average BCR 9:1 versus BCR 3:1 respectively (McKinsey 2013).

Figure 2.1 Comparison of returns for different road investments



Source: McKinsey 2013

This could be illustrated by the case study of the UK's M42 motorway where the cost of the ITS solution was $150 million and took two years to implement, while widening the road to produce the same outcome would have taken 10 years and cost $800 million. Similar opinion is expressed by Ezell (2010) who states that ITS can deliver superior benefit-cost returns when compared with traditional highway investments.

The UK Department for Transport ITS Toolkit (UK DfT 2015) states that ITS can make travel more efficient, safer, less polluting, can simplify public transport use by providing real time information and improve integration between different traffic management systems. Various examples of the achieved benefits are quoted. For instance the time spent searching for parking space in Southampton was cut by half. The congestion charge schemes in London reduced the numbers of cars entering the zone daily by 70,000, while the numbers of cars entering the Western Extension were reduced by 30,000.

In 2014, the Florida Department of Transportation set the BCR of 10.08 as the new base line for ITS projects. This was based on the average BCRs returned by the ITE projects during the last 10 years. They apply a 15-year analysis period and a 7% discount rate (Florida DOT 2014).

Figure 2.2 Benefit-cost ratios returned by ITS projects

Source: Florida DOT 2014

European sources show the BCRs of ITS installations around 2.0 –3.0 (European Commission 2013). McCombs and Wee (2007) cited an FHWA study (Jones 2004), which concluded that only 30% of information technology projects are successful, at times with moderate delay or overspending. The failure of the other projects is mainly due to deficient planning. The quoted FHWA study of information technology is an indication, but does not directly apply to the ITS projects.

ITS maximise the capacity of infrastructure, reducing the need to build additional highway capacity.

ITS rely on traffic surveillance. The goal of traffic surveillance systems is to supply information about conditions in the field to other system components so that appropriate response and control actions can be taken. Monitoring and traffic surveillance strategies include the use of closed-circuit television (CCTV), system detectors and communications networks. These tools can help improve incident management, inform control decision-making and determine traffic conditions for information dissemination (Bertini et al 2005).

Collecting the real-time data needed to measure and improve the performance of the transport system makes ITS the centrepiece of efforts to reform surface transportation and hold providers accountable for results (Ezell 2010).

According to Ezell (2010) ITS delivers five key classes of benefits by: 1) increasing safety, 2) improving operational performance and economic efficiency, particularly by reducing congestion, 3) enhancing mobility and convenience, 4) delivering environmental benefits, and 5) boosting productivity and expanding economic and employment growth. In the economic evaluation it has to be taken into consideration that the benefits of each of these classes overlap. The evaluator has to avoid the double counting of benefits.

2.3.1.5 Traveller information systems

General comments

Traveller information systems improve traveller's ability to make informed choices in terms of the time of travel, the appropriate route and the mode of transport. The traveller can access information when they plan the trip and during the trip.

Among other means, the dissemination of pre-trip travel information can be done through dedicated websites, telephone dial-in service, radio traffic reports, apps on mobile telephones or in-vehicle navigation devices.

The dissemination of end-route information can be conveyed to motorists through different means such as dynamic message signs (DMS), VMS or highway advisory radio (HAR). Dynamic message signs are constantly changing, to reflect such inputs as the speed of a vehicle, while VMS have static messages that can be changed through the operations centre. Some VMS are permanent while others are portable and may be moved to different locations (Bertini et al 2005).

ITS applications in travel information services strive to deliver accurate information to the motorist or traveller. The information services aim at allowing users to make more informed decisions about their trips either with pre-trip information or end-route information. These services have been shown to increase transit usage, and may help to reduce congestion on the roadways if motorists choose to leave early or postpone their trips based on the information they receive (Bertini et al 2005).

The European Commission report (2013) estimated the overall effect of road safety-related traffic information to provide an average reduction of 2.7% in fatalities and 1.8% in injuries, relative to all road crashes. The report presents only the overall results, without delving into the details of the road infrastructure, traffic volumes or the type of crashes.

The case study of travel on a 28km motorway revealed that supplying travellers with travel time information led to a significant reduction of travel costs amounting to €1.00 per trip (Ettema and Timmermans 2006).

The BCRs reported from the European ITS traffic information installations are shown in table 2.2:

Table 2.2 Benefit cost ratios of the deployment options

Deployment option	BCR (low cost estimate)	BCR (high cost estimate)
Road safety related traffic information disseminated to end users via existing delivery channels in some countries	1.09	0.22
As above, except ‘unexpected end of queue’ message	1.80	0.27
Road safety related traffic information disseminated to end users via existing delivery channels in all countries	1.01	0.20
As above, except ‘unexpected end of queue’ message	2.58	0.25

Source: European Commission 2013

The European Commission report (2013) states that detection of the unexpected end of queue is most expensive with the current technologies available, bringing relatively low additional benefits.

Ezell (2010) reports on a 2005 study of a model ITS deployment in Tucson, Arizona, consisting of 35 technologies including highway advisory radio (HAR), dynamic message signs, a telephone and web-based traveller information system and kiosks. The study found that the implementation would deliver an expected 6% decrease in congestion, a 70% decrease in incident-related delay on freeways, and would decrease an average annual travel time in the studied network by seven hours per resident.

The environmental impact of the implementation anticipated reduction in annual fuel use by 11% and reduction in annual carbon monoxide, hydrocarbon and nitrous oxide emissions between 10% and 16%. The expected average annual cost for implementing, operating and maintaining all 35 ITS technologies was estimated at US$72 million, while the expected average benefit from the ITS deployments to mobility, the environment, safety and other areas was estimated at $455 million annually. In total, the Tucson study estimated that the benefits of deploying ITS outweighed the cost by 6.3 to 1 (GAO 2009, quoted by Ezell 2010).

Pre-trip travel information – general comments

The benefits of using pre-trip travel information have been demonstrated by various sources. Many drivers use such information. Khattak et al (1996) studied radio reports and concluded that 60% of travellers in San Francisco would change the route or mode, leave earlier or later or cancel the planned trip on the basis of the pre-trip information. The remainder of drivers either do not access such information or do not react to the messages. A simulation study in Taiwan reported that approximately 30% of travellers would switch the route if advised, but another 30% would not pay attention to the messages (Jouet al 1997).

A simulation study In the Washington DC region in 2001 quoted by US DOT (2015a) indicated that commuters who use real-time travel time information to plan routes and departure times during peak periods can improve on-time reliability by 5% to 16%. A review of travel time reliability (Bates et al 2001) established the cost of unreliability of information, which ranged between 25c/min and $1.30/min (converted to NZ dollars from pounds sterling).

In the Washington DC metropolitan area drivers who use route-specific travel time information can improve on-time performance by 5% to 13%. However wide-area traffic advisories are less effective. The study, quoted by US DOT (2015a), used an analytical technique to quantify the mobility benefits of listening to radio traffic advisories and compare them to those of a prospective traveller information service designed to provide door-to-door estimates of real-time travel times.

A 1999 survey of travellers in Cologne, Germany, quoted by US DOT (2015a), indicated that workers and commuters travelling a distance of 40km or more were willing to pay more for traveller information services than shoppers and commuters travelling a distance of 5 to 10km.

Pre-trip travel information – websites

The Oregon DOT's state wide traveller information website was launched in 2000. It provides images from CCTV cameras showing traffic conditions, incident reports, speeds on the highway network, road construction activities and weather forecasts. Telephone interviews conducted in 2001 showed that 60% of commuters used the website, with 83% of them confirming that the information was 'somewhat or very important' to them (Oregon DOT 2004).

Auckland Transport has a website that contains full timetables and guides for all public transport services in Auckland (Auckland Transport 2015). In addition to the timetables it provides real-time information on traffic congestion in Auckland streets, parking availability, cycling and walking routes, and roadworks.

The Transport Agency website provides information on the latest highway conditions on the state highway network all over the country (NZ Transport Agency 2015).

Pre-trip travel information – telephone dial-in

In Cincinnati, Ohio, telephone surveys of area travellers revealed that two thirds of travellers were 'satisfied' or 'very satisfied' with the regional system of information on highway conditions. Information is available 24/7 by dialling in. The information helped them to avoid traffic problems, save time, reduce frustration and arrive at their destination on time (Clemons 1999).

In 2004, 92% of users surveyed in the San Francisco Bay area were satisfied with the dial-in information service 511, while in Montana 90% were satisfied. On I-81 corridor in Virginia 99% of users surveyed said they would call again. The 511 model deployment evaluation project in Arizona in 2005 found that 71% of users were satisfied. In Washington State satisfaction levels were high, as 87% of the callers said they would call again (US DOT 2015a).

A survey of travel advisory telephone service in San Francisco reported by Mehndiratta et al (2000) revealed that the respondents were willing to pay US$5.81 monthly for having the information on their route continuously updated, but only US$5.12 for information updated every five minutes. Willingness to pay for information on the complete network coverage was much lower at US$2.57.

En-route travel information – general comments

Advanced traveller information systems (ATIS) provide real-time traffic information to road users and aim to manage their mobility more efficiently. Current data collected by such devices as inductive loops and floating cars, historical data and predicted data form the basis of ATIS.

The results of a simulation of ATIS installed on a transport corridor in Los Angeles reported by Al-Deeket al (1989) indicated that under the non-recurring, incident congestion scenario (where the incident was on the freeway), travel time savings from choosing the shortest path were found to be significant (greater than three minutes) during certain times in the analysis time frame. The greatest travel time savings accrued during the time slices immediately following the incident, with a maximum saving of 10 minutes for a 30-minute trip. The length of the corridor was not provided.

The reliability of conveyed information is important. Kantowitz et al (1997) found that when the information provided was accurate at least 70% of the time, most of the drivers would utilise the ATIS messages. When the accuracy dropped below 40% the drivers would not rely on ATIS but on their knowledge of the route.

Khattaket al (1994) reported that annual monetary benefits from the diversion induced by ATIS in the Golden Gate Bridge corridor ranged from US$124 to US$324 per person, varying linearly with the weight assumed for delay. These figures applied to about 40% of the commuting population in the corridor.

Hamerslag and van Berkum (1991) found that in all cases the total vehicle-kilometres of travel (VKT) decreased with increases in the level of travel time certainty, as the spatial distribution of trips adjusted to the changed perceptions. The authors concluded that information provision may reduce VKT by 15% to 20% in urban networks and by 5% to10% in regional networks.

A good example of the benefits of the end-route information is the vehicle information and communication system in Japan (VICS). It provides drivers with detailed real-time traffic information on traffic congestion, traffic incidents, roadworks and parking availability. Information is processed at the VICS Centre and then transmitted in real time to car navigation systems. VICS enables drivers to select the shortest, most convenient routes available and ensures that traffic is distributed smoothly. Simulations indicate that if 20% of the drivers on the metropolitan highways use VICS, the congestion will be reduced by 10% (Chen and Miles 1999).

Lappin and Bottom (2001), however, discussed possible adverse effects of guidance dissemination. When a significant number of drivers receive identical message, they can react in the same way, which in turn can cause overreaction and congestion on the alternative route. The distinct possibility exists that providing guidance may worsen traffic conditions. This can be addressed if other alternative routes are available, which is not often the case.

En-route travel information – variable message signs

Electronic VMS are a means of communicating traffic instructions, traffic flow and road conditions to motorists end-route. A study by Benson (2001) examined the benefits of 100 VMS installations in Northern Virginia. He was not able to quantitatively evaluate actual changes in driver behaviour and therefore to assess the benefits he used public opinion surveys. He found that 50% of respondents regularly relied on VMS and 60% of them were very likely to use VMS recommended routes in cases of severe congestion ahead.

A study in Glasgow, Scotland (FHWA 2003),quoted by Bertini et al (2005), showed that up to 90% of travellers noticed VMS, and 40% of respondents said they changed their routes as a result of the message.

Economic evaluation of the application of VMS on rural highway incidents was conducted by Resolve (2007) in New Zealand. It was based on the potential reduction of crash costs and saving of travel time. The analysis used the EEM methodology. Whereas the project capital costs and maintenance costs were based on solid engineering estimates, several assumptions had to be made regarding the percentage of vehicles affected, closure duration, travel time saved and crash reduction rates.

The resulting BCR was 16. However the Transport Agency peer review challenged these assumptions arguing that since alternative rural routes were long and of low standard there was no reason to expect a reduction in crashes, while vehicle operating costs would increase. Although they agreed with the travel time savings, their analysis demonstrated that with another set of assumptions the BCR could be as low as 1.2.

Changeable message signs (more commonly known as VMS) are reported to reduce travel time in the range of 7% and 18% in Turin and 22% in London (Nielson 2003). A study of provision of travel time information signs on the M3 motorway in Brisbane (Dia et al 2012) investigated several options of the VMS locations. The cost of the preferred option was $4.4 million. The estimated annual benefits were $10.9 million, producing the BCR of 2.5. Benefits were estimated using a traffic model and included improved travel time reliability, reduced user costs from improved ability to plan or modify trips and reduced congestion. Savings in pollutant emissions, vehicle operating costs, reductions in crashes and other more difficult-to-quantify benefits (such as driver comfort and enhanced experience) were not included.

2.3.1.6 Control and management of traffic flow

Adaptive and advanced signal control

Adaptive signal control technology uses real-time traffic information to cut costs and reduce congestion, improve traffic flow and reduce vehicle emissions. It collects and evaluates traffic data and uses the data to develop and implement signal timing to improve traffic flow. By continually collecting information and updating signal timing to reflect current traffic conditions, it can respond to traffic incidents, special events, recurring traffic congestion and construction impact to reduce delays and improve system efficiency. A search of the US Department of Transportation benefits database for adaptive signal control technology yields a wide range of % reductions in delays, fuel consumption and labour costs (US DOT 2015a). Benefits from hundreds of projects are cited but the basis of calculation of the benefits on individual projects is not stored in the database.

A report from the Information Technology and Innovation Foundation, an independent US think tank that promotes new ways of thinking about the use of IT, contends that applying real-time traffic data to US traffic signal lights can substantially improve traffic flow. This is achieved through reducing stops by 40%, reducing travel time by 25%, cutting fuel consumption by 10% and cutting emissions by 22% (cutting daily carbon dioxide emissions by 9, 600 tons). Overall, ITS can reduce congestion by as much as 20% or more (Ezell 2010).

Re-timing a system of traffic signals during a two-phase project in Oakland County, Michigan resulted in carbon monoxide reductions of 1.7% and 2.5%, nitrogen oxide reductions of 1.9% and 3.5%, and hydrocarbon reductions of 2.7% and 4.2% (Bunch et al 2011).

A study using the ITS deployment analysis software (IDAS) was conducted in Eugene, Oregon to evaluate the potential benefits of a hypothetical future adaptive signal control system along Gateway Street at eight signalised intersections for improved travel time (Bertini et al 2005). The results were summarised in a benefits-to-cost summary and are shown in the table below.

Table 2.3 Potential benefits of adaptive signal control system in Eugene, Oregon

Performance measure annual benefit	Annual benefit for all travellers
User mobility	$135,000
Fuel consumption	$1,000
Emissions	$10,000
Total annual benefits	$146,000
Total annual costs	$27,500
Benefit-to-cost ratio	5:1

Source: Bertini et al 2005

'User mobility' in table 2.3 is advocated by FHWA in place of the more familiar travel time measure. User mobility is calculated using zone-to-zone travel times and the number of trips between zone.

With regard to implementation of specific ITS systems, a study of 26 traffic signal optimisation projects in Texas found that signal optimisation benefits outweighed costs by 38 to 1 (Ezell 2010), although no details of the study were provided.

The US Department of Transport website has a cost database for different types of ITS, for example signal controls. A 2014 national study in USA estimated that average hardware costs to upgrade signal controllers for connected vehicle purposes may be as little as US$3,200 per site. Installation of adaptive traffic signal control costs in the range of US$20,000 and US$80,000 per intersection, depending on the sophistication of the equipment (US DOT 2015b).

Coordinated traffic signals are reported as saving between 8% in travel time in Toronto and 20% in Michigan. The differences in the reported measures could be attributable to differences in traffic volumes, local driver behaviour, road configuration, or statistical sampling techniques. It is these differences that make it imperative that those using the measures ensure the circumstances are as consistent as possible (Nielsen 2003).

Ramp metering

Ramp signalisation has proven to be an effective means of control to prevent bottleneck formation at critical ramp junctions, increasing efficiency and safety. At the most basic level, ramp meters are traffic signals located at motorways on-ramps to control the flow of vehicles onto the motorway.

Based on a pre-defined or variable signal cycle, vehicles are allowed to enter the freeway only on a green indication. The rate is determined through either real-time or historical knowledge of the freeway capacity and the demand of the on-ramps (Bertiniet al 2005).

An evaluation on the effects of a weekend ramp meter shutdown on US Highway 26 indicated that ramp metering led to increased quality of service travel through the corridor. As a result of ramp metering the proportion of travellers who spent their time in level of service D, E and F dropped from 42% to 39% during Saturday travel, and from 37% to 32% during Sunday travel. The studies also concluded that improvements in efficiency could be gained by better ramp detection installed in future implementations of ramp metering. A 1982 report for ramp metering from Oregon DOT showed a 65% reduction in travel time and a 43% reduction in crashes on Interstate 5 (Bertini et al 2005).

In Denver, freeway ramp meters were reported to reduce crashes by 50% and in Portland by 13% (Nielsen 2003). Kang and Gillen (1999) quoted in Nielsen (2003) reported substantial speed increase and crash reduction in several US cities. The most representative are the results of a large-scale study conducted in Minneapolis, where 367 ramp meters affected vehicle movement on the freeway network 259km long. The speed increased from 55km/h to 75km/h and the number of crashes reduced by 27%.

Ramp signalling installation costs (costs of electronic equipment, signs, cabinets, cables, connections, etc) on SH20 to SH1 in Auckland would range between $250,000 and $400,000. The cost depends on the complexity of the site. This is the price per site and usually an interchange contains two ramp-signalling sites.

An evaluation of the performance of ramp metering in Auckland (Brown et al 2005) conducted at the Mahunga Drive on-ramp on SH20 demonstrated that the throughput on the motorway lanes increased from 3,400veh/h to 4,000veh/h (a 15% improvement) and an average speed increased from the range of 25km/h – 35km/h to the range of 40km/h – 50km/h. This was accompanied by an increased duration of the queues on the approaches, although the queue length did not increase.

Arterial management systems

Portland State University undertook a literature review based on documented experience locally and throughout the US. The review found that arterial management systems manage traffic by using traffic signal control, detectors, closed-circuit television (CCTV) cameras, ramp signals and VMS to improve the efficiency of roadways. Arterial management systems can potentially reduce delays between 5% and 40% with the implementation of advanced control systems and traveller information dissemination. Freeway management systems can reduce the occurrence of crashes by up to 40%, increase capacity and decrease overall travel times by up to 60% (Bertini et al 2005).

In 1995 the first phase of the San Antonio TransGuide System became operational. The system included 26 miles of downtown freeway with dynamic message signs, lane control signs, loop detectors, video surveillance cameras and a communications network.

Post-implementation monitoring revealed the impact of the system on crashes and incident response times during the first five months. Crash statistics were compared for August – December of 1992, 1993 and 1994 with the statistics for August – December 1995. The before-and-after study indicated that the system reduced primary crashes by 35%, secondary crashes by 30%, inclement weather crashes by 40% and overall crashes by 41%. These results may not be typical given that only one year of after data was studied. Data collected through 1995 indicated a 20% average reduction in response times as a result of improved traffic surveillance and incident response (Bertini et al 2005).

In one study, researchers at Florida International University found that the $9.9 million annual cost of a traffic operations management system in Broward County, Florida, yielded a benefit of $142 million in reduced travel time, fuel consumption, emissions and secondary crashes involving rubbernecks. This constituted the BCR of 14 (Ezell 2010).

2.3.1.7 Early detection and management of incidents

The key components of the incident detection system are the sensors, such as loops, radar or CCTV cameras. A US DOT database (2015b) presents examples of the costs associated with the incident detection and management. For instance the cost of CCTV cameras and their connection to a central signal control system ranges between US$14,000 and US$18,000 per location. The cost of setting up a traffic management centre and the installation of the associated ITS field equipment for a small US town (population 20,000) ranges between US$450,000 and US$850,000.

Four CCTV sites (CCTV camera, CCTV pole, cabinet, etc) were installed in Auckland for approximately $200,000 in total. The cost range was $41,000 to $74,000 per site, with an average price of $50,000.

Approximate costs of ITS equipment in Europe are shown in table 2.4:

Table 2.4 Capital and maintenance costs for different types of equipment

Equipment	Average life cycle (years)	Approximate capital cost (€)	Maintenance cost (€/device- year)
Inductive loops	5	3,000 - 8,000	500
MIDAS loops	5	12,000	640
Camera CCTV	10	54,000	640
Road weather stations	15	35,000	600
Radar sensors	5 – 7	8,250 – 12,000	165
Reception of PSAP data	One-off cost	100,000	N/A

Source: European Commission 2013

Incident management systems can broadcast information about incidents to travellers suggesting alternative routes and broadcasting information through the media, HAR, and variable message signs that can reduce congestion and traveller delay. Incident management also includes improving the efficiency of hazardous materials response.

Incident management programmes can reduce the effects of non-recurring congestion by decreasing the time to detect incidents, reducing the time for responding vehicles to arrive, thereby reducing the time to return the facility to normal conditions. Congestion caused by incidents is estimated to cause approximately 50% of congestion delay on the USA national highways. Bertini et al (2005) concluded that the incident management systems potentially reduce incident duration by 40% and offer numerous other benefits, such as increased public support for DOT activities and goodwill.

In March 1997, the incident response programme known as COMET was set up in the Portland metropolitan area. The components included VMS, basic traffic control equipment, a communications system and an automatic vehicle location (AVL) system. During a given weekday four response vehicles were operating, while two vehicles operated on weekends and overnight. The annual cost to operate COMET was about $750,000 (Bertini et al 2005).

An estimation was made of the actual delay caused by the incidents responded to by COMET. Table 2.5 shows the total hours of delay for the incidents, as well as the costs of fuel consumption and time. In addition, the table shows how the values would be affected by durations that were 1, 5 or 10 minutes over the actual delay recorded from COMET.

With the assumption that without COMET the incident would increase in duration by one minute the total cost of delay increases by $1,423,000; or roughly twice the cost of operating the COMET programme for one year. If the delay was increased by five minutes then the cost rises to $7,113,000. With a 10-minute increase in delay the cost would rise by $14,226,000. The data indicated that an average reduction in delay by about only 30 seconds per incident is the break-even point for costs and benefits of the program.

Table 2.5 Cost of incident due to delay, Portland, Oregon

Measurement of performance	Actual annual incident delay	+ 1 minute per incident	+ 5 minutes per incident	+ 10 minutes per incident
Hours of delay	1,940,000	1,994,000	2,211,000	2,481,000
Fuel consumption	$2,522,000	$2,593,000	$2,874,000	$3,226,000
Time	$48,484,000	$49,836,000	$55,245,000	$62,006,000
Total annual costs	$51,006,000	$52,429,000	$58,119,000	$65,232,000

Source: Bertiniet al 2005

These potential benefits of the incident detection and management appear to be conservative in view of the data recorded elsewhere. For instance, an evaluation of Maryland incident management programme showed the reduction of average incident duration from 77 minutes to 33 minutes (Pretrov et al 2002), which by far exceeds the 10-minute saving considered as a maximum by the Oregon study.

Similar results were reported for the Toronto COMPASS traffic monitoring and incident information dissemination system, where the average incident duration decreased from 86 to 30 minutes (US DOT 2015a).

In 2010, the New Jersey Department of Transportation enhanced incident management efficiency by using I-95 Corridor Coalition's Vehicle Probe Project data, experiencing an estimated savings of $100,000 per incident in user delay costs (US DOT 2015a).

With the ongoing development of new technologies in personal communications, eg iPhones and apps, different ways of dealing with incidents now exist and will continue to evolve. The traditional roadside structures on the network housing detection equipment have now been supplemented by GPS and other in-vehicle technology that can be used to detect incidents. The merits of new technologies for use in incident detection and management are discussed below.

In Europe, eCall is an initiative that will allow a motorist to either automatically or manually communicate with a public service answering point (PSAP) when an incident occurs. PSAP then notifies appropriate emergency service organisations so they can respond quickly to the situation. During this communication process, PSAP personnel will assist the reporting vehicle operator in addressing immediate needs at the scene of the incident.

In 2005, the European Commission adopted a plan to equip all new cars in Europe with *eCall* as soon as 2009. eCall would join already deployed cellular communications systems with GPS, facilitating precise location of incidents as soon as they occur. It was anticipated that 2,000 lives a year would be saved in Europe as response times would reduce by up to 50% in rural and 40% in urban areas (FHWA 2006).

The North Carolina DOT utilised its traffic monitoring budget more effectively by using vehicle probes in order to increase the needed coverage. Typical remote traffic microwave sensors, costs of equipment, installation and maintenance came to approximately $48,600 per mile. Vehicle probes saved money by replacing the microwave sensors at about one quarter of the cost, allowing the agency to increase the coverage area.

Similarly, the South Carolina DOT cited cost efficiencies in the agency's use of vehicle probes over side radar detectors. The cost of maintaining its radar coverage over 300 miles was equal to the total cost of the vehicle probe data covering 1,200 miles, with probes having the added benefit of transmitting travel time as well as speed data. These findings were published in 2010 (US DOT 2015a).

2.3.1.8 Public transport management

Real-time passenger information

Real-time passenger information can be accessed by phone, on the web, on a mobile device or displayed on a dynamic message sign at bus stops. For example TriMet Transit Tracker in Portland, Oregon, gives real-time arrival information for buses and trains. Using satellite tracking Transit Tracker estimates the arrival time of the next vehicle, based on its last reported location. A survey of passengers revealed that the value placed on Transit Tracker was very high, with 4.5 points on a 5-point Likert scale.

Forty-two percent of travellers most valued knowing how many minutes they had to wait until the bus arrived (Bertiniet al 2005). In addition, bus service on-time arrival performance improved from 78% to 83%. Hu et al (2002) identified the main benefits of Transit Tracker as reduced and eliminated manual counts, improved data and schedule reliability, and better incident tracking.

Studying the economic efficiency of the real time passenger information system at bus stops in Auckland Tomecki et al (2002) obtained the BCR of 5.0 based on the results of the willingness-to-pay surveys of bus travellers. Willingness-to-pay gave values of 10c per passenger on top of the regular fare. The second part of the benefits was bus time savings at intersections with pre-emption; it was calculated to be 10 seconds or approximately two cents per passenger per intersection.

Signal pre-emption at intersections

Transit (public transport) signal priority (TSP) is effective for improving the on-time performance of buses or light-rail vehicles. TSP allows buses that are behind schedule to increase the length of a green phase, shorten the length of a red phase or shorten opposing phases of a traffic signal and proceed through an intersection.

TSP enhances the reliability of bus service, improving both customer satisfaction and the efficiency of the transit operation, resulting in cost reductions for public transport service providers. TSP systems require close collaboration between the transit provider and the local agencies that have jurisdiction over the arterials and traffic signal system (Bertini et al 2005).

A public transport priority system implemented on an urban bus line in Vancouver, British Columbia, has decreased the variability of travel time experienced by buses along the route by 29% in the morning peak hours and 59% during the evening peak hours. A study performed in Seattle, Washington on a TSP implementation on

Rainier Avenue showed that average bus delay was reduced by approximately five seconds per TSP equipped intersection, signal-related stops were reduced by 50% for TSP equipped buses, bus travel time variability was reduced by 35% and transit patrons experienced a smoother and more comfortable ride (Bertini et al 2005).

Automatic vehicle location systems and computer aided dispatching

Automatic vehicle location (AVL) systems and computer aided dispatching systems allow public transport agencies to optimise vehicle resources, providing valuable information for operational control strategies that reduce the number of vehicles necessary to provide the required level of service (Bertini et al 2005). Real-time information systems also use AVL technology such as GPS to locate public transport vehicles in real time. The information provided by AVL can be then be used for fleet management and optimisation of services using software and systems developed for that purpose.

Public transport management systems may reduce travel times by up to 50% and increase reliability by 35% with AVL and public transport signal priority implementation. After the implementation of an AVL system, the Denver Regional Transportation District found that between 1992 and 1997 there was a 12% decrease in the number of vehicles that arrived early at stops and customer complaints decreased by 26% per 100,000 boardings (Bertini et al 2005).

Integrated ticketing

Auckland integrated fares system, branded AT HOP, is the creation of an integrated smartcard ticketing system that can be used on trains, ferries and most buses. The technology is some 20 years old, since the first successful implementation of the Octopus system in Hong Kong. Current integrated ticketing is based on the use of a smartcard, which allows for the storage of complex journey information enabling flexible ticketing across various public transport modes and companies.

One of the most important developments in integrated ticketing is the ability for the account-based systems to use standard credit and debit cards as access tokens. This has been demonstrated in London and Chicago. Significant benefits to this approach are that it does not require pre-purchase and top-up of a transport specific card; it is managed by financial institutions reducing the complexity and card management costs, and public transport is immediately accessible to visitors and tourists.

The benefits of simplified and integrated ticketing (Booz 2009) comprise increased patronage, increased revenue, support of modal shift, increased passenger satisfaction, faster boarding times, reduction in fraud and reduction in administration costs.

For example, since the introduction of integrated ticketing, patronage in London has increased by 32% across all modes (between 1999 and 2005), in Freiburg by 7.5% annually, in Zurich by 12% (over a two-year period). Significant revenue increases above 10% were recorded in Maryland. An increase in passenger satisfaction was observed in several European and American cities. These increases were mainly attributed to the convenience of fare payment, savings on purchased tickets and simplified fare structures.

An AECOM study of the use of smartcards in public transport ticketing (Paddington 2011) revealed high BCRs over 10 years of the project lifecycles in a raft of European cities, ranging from 5.6 to 7.8.

2.3.1.9 Parking systems

A smart parking system at the Rockridge BART station permitted pre-trip as well as end-route trip planning. Motorists could reserve a parking space at the station up to two weeks in advance. While end-route and faced with road congestion, they could see the display of real-time parking availability at the station lot and decide to use public transport.

The evaluation study estimated that the capital costs for deploying such a smart parking system would be between US$150 and US$250 per space, with annual operations and maintenance costs ranging from US$50 to US$60 per space (US DOT 2015b).

A 2006 study of advanced parking management systems (APMS) at six facilities in Baltimore, Chicago and Seattle concluded that the cost could range between US$250 and US$800 per space. An APMS provides directions to the parking facility and information about space availability. The elements of the system are the sensors, display units, operating software, electronic payment system, power supply and communications (US DOT 2015b).

The Seattle Centre Advanced Parking Information System in Seattle, provides information and routing directions to three major parking garages via VMS. This information is also available via the Internet, phone, and pagers to travellers prior to leaving for an event as well as travellers' end-route. Detection technology is used to monitor parking availability.

The system capital costs were US$925,000, while operations and maintenance costs were $50,000. Parking management staff was assumed to be 0.25 (US$30,000) full-time equivalent per year (US DOT 2015b).

Systems such as these provide benefits such as reducing time spent hunting for car parks (thereby reducing volumes of cars on road) and encouraging people to consider using other modes before they leave home as they can check on parking availability beforehand.

2.3.1.10 Enforcement

Speed enforcement by stationary cameras

France is making a clear effort to address excessive speed and its contribution to injury and fatality crashes. One system is an experimental speed control effort on the A7 motorway operated by Autoroutes du Sud de la France. Speeding violations decreased from almost 7% to less than 3% in areas where camera enforcement was in operation. In addition, these sites showed a dramatic 85% reduction in crashes in the 10-month study period. The French Ministry also noted a general decrease in speeding violations elsewhere on the motorway network, even in locations with no cameras.

Public reaction to the cameras includes an admission by 86% of drivers that their speed reduction was a consequence of the presence of the speed cameras and recognition by 77% that this automated speed enforcement system improved road safety (FHWA 2006).Installation of 600 speed cameras in the UK in 2003 cost £35K per installation (US DOT 2015b).

Point-to-point speed enforcement

The Netherlands Department of Traffic Prosecution has committed itself to installing a new system of speed over distance enforcement (SDE) on the country's major roads. A trial installation on the A13 near Rotterdam, with the maximum speed reduced from 100km/h to 80km/h and enforced by SDE has not only reduced crashes but produced a noise reduction of over 3dB(A) in a residential area extending up to 200m from the highway. There has also been a reduction in emissions of between 15% and 25% NO_x per vehicle (Chen and Miles 1999).

Lynch et al (2011) discussed the potential of using point-to-point (P2P) speed enforcement in New Zealand and reviewed some international applications. They reported a 46% reduction in fatal crashes on a 50km long stretch of A77 in Scotland, a 60% reduction in fatal crashes on A428 in Northamptonshire, and an 82% reduction of fatal and serious injury crashes on A616 in South Yorkshire.

There are several sources of potential benefits from P2P systems, and the potential for benefits to accrue both to society as a whole and to the operator of the system, including crash reduction and vehicle operating cost savings. The primary objective of the P2P system is to improve road safety. Therefore, the primary benefit to be considered when planning the implementation of P2P speed enforcement is the potential crash reduction. There are two types of costs that are considered when forming the estimate for whole-of-life costs: capital costs and recurrent costs. Assuming an installation contains roadside infrastructure – four pole-mounted cameras to cover two dual carriageway lanes in each direction, a roadside cabinet and automatic number plate recognition processor, the estimated capital costs are $1.1million and estimated recurrent costs are $850,000 per year. Based on similar P2P speed camera implementation projects conducted in the Australian Capital Territory, where cost and benefit information is available, the results show the BCR ranges between 6.5 and 14.4. (Lynch et al 2011).

Not all speed violations recorded by the fixed cameras are processed as infringement notices. The Office of the Auditor-General's 2002 report on the New Zealand speed camera system stated only 59% of photos were processed as infringement notices. The equivalent rate in Victoria, Australia at that time was 80%.The local rate has increased in recent years to around 70%. Reasons for the rejection of images include the vehicle's number plate is obscured, there are two vehicles on a dual carriageway in the photo and the offending vehicle cannot be accurately defined, and the number plate is false (OAG 2002).

Red-light cameras

A nationwide FHWA study found in 1999 that the implementation of an electronic enforcement programme resulted in a 20% to 60% reduction of red-light violations (Hu et al 2002).

A speed enforcement camera demonstration program on Loop 101 Freeway in Scottsdale, Arizona decreased the total number of target crashes by between 44% and 54%, the total number of injury crashes by between 28% and 48%, and non-injury crashes by between 46% and 56% (Bunch et al 2011).

In 1998 the red-light cameras cost in the range of US$67K to US$80K per installation (US DOT 2015b). The installation costs include the cost of the camera and its housing, detectors, poles and wiring. These costs would be substantially lower now, since the costs of the cameras have been greatly reduced since 1998.

Baththana and Durdin (2014) reviewed the application of the composite speed and red-light running cameras overseas and proposed the methodology to identify the locations where such cameras could be located in New Zealand to the best effect. Quoting the research by others they stated that the red-light running and speed injury crashes at the intersections where the composite cameras were installed were reduced by 44% and the fatalities by 67%.

Auckland Transport (2011) evaluated the red-light camera trial in Auckland. The system installed in 2008 produced the following benefits – a 43% reduction in red-light running behaviour, an estimated 93% reduction in the social cost of crashes, and average decrease in running on red crashes, a significant reduction in infringements, an estimated BCR of 8.2, and the favourable acceptance of the system by the 75% of public.

Improved registration and insurance compliance

Approximately 200,000 vehicles in Arizona are either not registered or have expired registration, resulting in a revenue loss of $25 million a year. Approximately 11% of registered vehicles are uninsured. The automatic licence plate recognition (ALPR) technology was designed to photograph, identify and ticket a high percentage of non-registered and uninsured vehicles.

As a result during the first year of ALPR operation in 2008 US$15.5 million was recovered in registration fees and US$18.4 million in registration fines, and US$62 million in fines for uninsured vehicles. The system cost was US$10 million (costs of 416 cameras US$8.3 million and installation at US$1.7 million), returning the BCR of 9.6 over the life span of the equipment (US DOT 2015a).

2.3.2 Evaluation methodologies

Chen and Miles (1999) stated that ITS evaluation methodology needs to take account of the ITS scheme objectives, user needs and stakeholder expectations of the project. It should make use of quantified and qualitative measures that serve the various – often very different – needs of the decision makers, travelling public and affected non-users. The qualitative measures are identified as an intrinsic component of the ITS evaluation. These points are true of any economic evaluation, but particularly important for the evaluation of ITS projects where the benefits are not always readily quantified.

Newman-Askins et al (2003) of Queensland University of Technology prepared a review of the ITS evaluation methods. They noted that the evaluation of ITS projects is complicated by the presence of the unique variables which may be difficult to quantify, such as increased user satisfaction and comfort, improved availability or quality of information.

It is important that the evaluation technology includes rigorous sensitivity testing and does not imply false precision to the estimated impacts. The ITS evaluation methodology must allow comparison of ITS projects with non-ITS projects. This is standard for economic evaluation, as per the EEM.

Bristow et al (1997) quoted in Newman-Askins et al (2003) recommended the use of benefit–cost analysis where standard monetary values are available, multi-criteria analysis where monetary values are not available for major impacts, and cost-effectiveness analysis where monetary values are available only for costs but a specified impact is achieved. Cost effectiveness analysis compares alternative projects on the basis of their costs and a single measurable project impact.

In a study of VMS in Northern Virginia,Benson (2001) used the public opinion survey as an evaluation tool. Seven focus groups were held first to help in formulating the survey questions. These groups qualitatively assessed the impact of VMS messages in terms of reducing congestion and delay, increasing capacity and mobility, improving road safety and reducing crashes, cost of VMS relative to other options, environmental and institutional outcomes. In terms of safety, respondents were asked about their preferences for the type of messages displayed. The survey wanted to know if respondents thought it was a 'good idea' to post safety messages such as 'drive to survive'. There was general approval for this although this conflicted with a preference that VMS be limited to messages on road condition.

The importance of Benson's study is that he tried to establish a comparative platform for the monetised and non-monetised aspects of ITS– the solution to the problem verbalised later by Newman-Askins et al (2003). His solution for providing assessment of the impact of VMS messages was by establishing the focus groups and relying on their rating of the value of the messages.

Douglas (in press) took a rating scale approach to the benefits of public transport enhancements including real-time information. A willingness-to-pay exercise was also used to attach value to benefits. For bus stops, the overall rating was found to range from a low of 46% when no facilities were provided as assessed from a passenger perspective to 75% at bus stops where shelter, seating, real-time information and a timetable was provided. When valued, the willingness to pay from providing a shelter was worth 9% of fare, seating 3%, real-time information3% and a timetable 2%.

In a study of the economic efficiency of the real time display of the bus arrival time at bus stops in Auckland, Tomecki et al (2001) and Wong and Tomecki (2002) used the willingness-to-pay surveys of the bus passengers.

The North West Passage project in the USA (FHWA 2015) contained numerous ITS components. The need to evaluate them required the development of a dedicated evaluation methodology able to compare the importance of the components against each other, and to compare tangible outputs with the intangibles.

The applied methodology had three stages. The first stage (Tool 1) was the ITS prioritisation spreadsheet to rank multiple ITS technologies and provide initial scoring for their value. The potential of each technology was assessed in terms of six measures rated from 0 to 10: crash reduction, alleviation of congestion, increased throughput, improved traffic operation, improved reliability of traveller information and enhanced integration. The North/West Passage benefit–cost spreadsheet tool includes providing a quantitative analysis on the following ITS devices: dynamic message signs; road/weather information systems; CCTV; traffic detection. The tool includes all the standard costs and benefits (eg travel time savings, vehicle operating cost savings, safety benefits) but adds in DOT cost-savings as a benefit.

The second stage (Tool 2) was the benefit–cost spreadsheet applied when the valid sources of benefits were documented. The final stage (Tool 3) was the benefit–cost metadata to view a tabular summary of the impacts and set the threshold values. The rating was done by the panels composed of the representatives of the involved and affected parties. Using the panels to conduct mainly qualitative assessment was similar to the other evaluation studies.

On the topic of whether willingness to pay or willingness to accept is a more appropriate method for assessing ITS benefits, Guria et al (2005) found:

> *Large disparities between willingness to accept (WTA) and willingness to pay (WTP) based values of statistical life are commonly encountered in empirical studies. Standard economic theory suggests that if a public good is easily substitutable there should be no marked disparity between WTA and WTP values for the good, though the disparity increases with reduced substitutability. However, psychologists have shown that people often treat gains and losses asymmetrically and tend to require a substantially larger increase in wealth to compensate for a loss than the amount they would be willing to pay for an equivalent gain.*

2.4 Conclusion of the literature review

2.4.1 Introduction

The literature review found many examples of literature providing information on the benefits of ITS both qualitative and quantitative. However, very little material was found on specific methodologies comparing the value of monetised user benefits from ITS elements, such as real-time information display at the bus stops, with the monetised benefits from infrastructure improvements, such as travel time saving. The reviewed references generally make statements such as ‘VMS in Turin are reported to reduce travel time by 18%’, without providing any details of how the benefits were calculated.

2.4.2 Benefits and costs of ITS

2.4.2.1 Benefits

The reported main benefits of improved ability to make informed choices by travellers are tabulated below. (The tables in this section are not exhaustive but list the main reported benefits).

Table 2.6 Benefits of traveller information

Specific component of the information system	Measured benefits	Reported improvement	Benefits covered by EEM	References
Integrated system, in Europe	Reduction of fatal crashes	2.7%	Yes	European Commission 2013
Integrated system, in Europe	Reduction of injury crashes	1.8%	Yes	European Commission 2013
Integrated system, in Tucson, Arizona	Reduction of incident related delay	70%	Yes	Ezell 2010
Integrated system, in Tucson	Fuel saving	11%	Yes	Ezell 2010
Pre-trip information	Changing route leading to time savings, reduced driver frustration	30% – 60%	Yes	Khattak 1996;Jou 1997
Pre-trip information	Reliability	5% – 16%	Yes	US DOT 2015a
Pre-trip information websites and dial in	Satisfied travellers partially covered by the above benefits	70% – 80%	Partial by the above benefits	Oregon DOT 2004; Clemons 1999
Variable message signs	Changing route leading to time savings	30% – 40%	Yes	Benson 2001;Bertini 2005
Variable message signs	Travel time reduction	7% – 22%	Yes	Nielson 2003

Table 2.7shows the reported benefits of control and management of traffic flow by such measures as adaptive signal control, ramp metering, incident detection and management or parking systems.

Table 2.7 Benefits of traffic control and management

Specific component of traffic control and management	Measured benefits	Reported improvement	Benefits covered by EEM	References
Advanced signal control	Travel time saving	8% – 20%	Yes	Nielsen 2003
Incident management	Reduction in incident duration	40%	Yes	Bertini 2005
Incident management	Reduction in incident duration	77min to 33min	Yes	Pretrov et al 2002
Incident management	Reduction in crashes	41%	Yes	Bertini 2005
Ramp metering	Reduction in crashes	27% – 50%	Yes	Bertini 2005; Nielsen 2003
Ramp metering	Travel time saving	65%	Yes	Bertini 2005; Nielsen 2003
Ramp metering	Speed increase	55km/h to 75km/h	Yes	Kang and Gillen 1999
Parking management	Time to find parking	50%	Yes	DfT 2015

Table 2.8 shows the reported benefits of public transport management, which includes dissemination of real-time information, signal pre-emption at intersections, and automatic vehicle location systems and computer aided dispatching.

Table 2.8 Benefits of public transport management

Specific component of public transport management	Measured benefit	Reported improvement	Benefits covered by EEM	References
Vehicle location and dispatch	On-time arrival	78% – 83%	Yes	Hu 2002
Vehicle location and dispatch	Reliability improved	35%	Yes	Bertini 2005
Real time pre-trip information	Traveller satisfaction	42%	Partially covered	Bertini 2005
Signal pre-emption	Variability of travel time	29% – 59%	No	Bertini 2005
Signal pre-emption	Reduced delay	5s/intersection	No	Bertini 2005
Signal pre-emption	Reduction in stops	50%	No	Bertini 2005
Integrated ticketing	Patronage increase	7.5% annual	No	Booz 2009
Integrated ticketing	Revenue increase	10%	No	Booz 2009
Integrated ticketing	Benefit–cost ratios	5.6 – 7.8	No	Paddington 2011

The table below shows the benefits of enforcement by such measures as speed control and red-light violation enforcement.

Table 2.9 Benefits of enforcement

Specific component of the enforcement system	Measured benefits	Reported improvement	Covered by EEM	References
Speed enforcement	Reduction of violations	7% – 3%	Yes by following benefits	FHWA 2006
Speed enforcement	Crash reduction	85%	Yes	FHWA 2006
Speed enforcement	Noise level reduction	3db (A)	Yes	Chen and Miles 1999
Speed enforcement	Emission reduction	15% – 25%	Yes	Chen and Miles 1999
Red-light cameras	Reduction in violations	20%–- 60%	Yes by following benefits	Chen and Miles 1999
Red-light cameras	Crash reduction	44% – 54%	Yes	Bunch 2011
Red-light cameras	Injury crash reduction	44%	Yes	Baththana and Durdin 2014
Red-light cameras	Fatal crash reduction	67%	Yes	Baththana and Durdin 2014

Benefits and disbenefits

There is a general agreement expressed in the published material that ITS can bring substantial benefits. Nevertheless one has to be aware of possible pitfalls or overstating the benefits. For example Jones (2004) concluded that only 30% of information technology projects are successful. Although his conclusion does not directly apply to the ITS projects, one has to keep in mind that information technology provides the core of ITS applications.

Possible adverse effects of guidance dissemination were discussed by Lappin and Bottom (2001). They postulated that when a significant number of drivers receive the VMS message and react to it by selecting the same alternative route, this route can get congested and cause delays greater than the delay for vehicles staying on the original route.

A similar view was expressed by a Transport Agency reviewer commenting on the benefits of the VMS installation in Waikato claimed by a consultant (Resolve 2007). The evaluator produced the BCR of 16, which was challenged by the reviewer who argued that the alternative route was long and of low standard. He dismissed the evaluator's claim that the number of crashes would be reduced and the travel cost decreased. His revised BCR was 1.2.

Another example of potential disbenefits was noted by Brown et al (2005) who evaluated the performance of ramp metering at the Mahunga Drive on-ramp on SH20 in Auckland. Although the throughput on the motorway lanes and an average speed increased, their study noted an increased duration of the queues on the approaches.

Costs

As far as the costs are concerned, it is difficult to obtain more than a general idea from the literature. The costs depend very much on the local circumstances and the subtleties of the technology applied in each case, and the literature does not provide enough details to make valid comparisons of the various ITS applications.

2.4.3 Methodologies

The literature review revealed very little material on the topics of comparison of tangible and intangible values, and attaching monetised values to ITS elements such as provision of real-time information to travellers. Most of the studies focus on the surveys of the traveller satisfaction with the information provided or the technology used to provide it.

We note the multi-criteria approach taken in other jurisdictions in contrast with the EEM cost–benefit analysis approach. The use of multi-criteria analysis where monetary values are not available is recommended by Bristow et al (1997). They also recommend the use of cost-effectiveness analysis where the cost of the alternatives to achieve a similar output is known. A similar approach is recommended by the UK government (DfT 2014). They recognise that it could be impractical to derive monetary values for some impacts and advise that the most common technique where there are unvalued costs and benefits is weighing and scoring, or multi-criteria analysis. A similar sentiment is expressed by the Australian Government (BITRE 2007)

A qualitative assessment of the outcomes by public opinion surveys was used by Benson (2001), while Bertini et al (2005) used customer satisfaction rating to assess the quality of service or expectation of benefits. The methodology applied for the North West Passage project (FHWA 2015) also used the qualitative rating of the expected benefits. This made possible comparisons of the value of, for instance, reduction of crashes (monetised) with reliability of traveller information (non-monetised).

In an Auckland study of the efficiency of the proposed real-time passenger information system (Wong and Tomecki 2001; Tomecki et al 2002) the willingness-to-pay surveys were applied to travellers at bus stops to derive the monetised value of such system.

In conclusion it can be stated that the assessment of the non-monetised values can be done by public opinion or peer group surveys or willingness-to-pay surveys. By applying qualitative ratings to both monetised and non-monetised aspects of ITS the comparisons between them could be made. However, very little material was found on specific methodologies comparing the value of monetised user benefits from ITS elements with the monetised benefits from infrastructure improvements, such as travel time saving.

3 Review of the *Economic evaluation manual* (EEM)

3.1 ITS functionalities which can be adequately assessed through the EEM

ITS functionalities that enhance the performance of transport network can be adequately assessed by the procedures contained in the EEM. Our appraisal of these procedures versus the following examples of ITS technologies can be summarised as follows.

Adaptive and advanced signal control and *arterial management* reduce travel time or delay, reduce crash costs, reduce vehicle operating costs and improve service reliability. The outcomes can be measured. The applicable evaluation procedures include the travel time analysis (EEM appendix A4:'Travel time' and appendix A4.4:'Traffic congestion'), crash costs (EEM appendix A6), vehicle operating costs analysis (EEM appendix A5) and trip time reliability analysis (EEM appendix A4.5:'Improved trip time reliability').

Ramp signalisation (metering) reduces travel time, and the number of merging crashes. The outcomes can be measured. The applicable evaluation procedures include the travel time analysis (EEM appendix A4) and appendix A4.4) and crash analysis (EEM appendix A6).

Early detection and management of incidents ensures an immediate warning can be given to travellers about the incident, reduces the time needed for rescue services to arrive on the scene to clear the incident and thus the delay to traffic, and reduces the number of secondary rear end crashes.

The outcomes can be measured. The applicable evaluation procedures include the bottleneck analysis (EEM subsection A3.19 'Bottleneck delay'), travel time analysis (EEM appendix A4) and crash analysis (EEM appendix A6).

Traffic signal pre-emption for buses reduces bus delay at the intersections, number of stops on the route and improves service reliability. These effects are measurable. The applicable evaluation procedures include the analysis of additional travel time due to speed changes (EEM appendix A3.21:'Additional travel time'), travel time analysis (EEM appendix A4), reliability analysis (EEM appendix A4.5) and vehicle operating cost analysis (EEM appendix A5).

Parking management systems guide drivers to the nearest available parking space. Such a guidance results in the reduction of time spent on looking for parking. When the effect is measured, the value of travel time cost saving can be assessed using the travel time analysis (EEM appendix A4). However measuring this effect might not be straightforward for an established parking system.

Automatic vehicle location and computer aided dispatching allow public transport operator to optimise vehicle resources leading to the reduction of vehicles on the route or increase in service frequency. The monetary benefits of the travel time reduction can be assessed using travel time analysis (EEM appendix A4).

Speed enforcement and red-light cameras improve the road safety. The resulting reduction in the number of crashes is measurable. The applicable evaluation procedure is crash analysis (EEM appendix A6).Details of the relevant sections of the EEM for evaluating ITS are given in section 3.2.

3.2 EEM procedures applicable to evaluation of ITS

3.2.1 Introduction

The EEM sets out the procedures for the economic evaluation of transport activities seeking funding from the Transport Agency. The procedures are multi modal covering different types of transport activities including roading, public transport, walking, cycling, transport demand management (TDM) and travel behaviour change. The EEM is principles based but also sets out standard values for benefit values such as travel time and crash costs. While ITS is not specifically mentioned in the EEM at present, evaluations of ITS, such as real-time information, have been successfully carried out using various clauses in the manual. These clauses are discussed in this section.

3.2.2 Subsection 1.2: Objectives and principles

This section states that there is no perfect methodology to determine the economic efficiency of an activity, but the EEM attempts to standardise techniques to ensure a fair comparison between activities. Furthermore it says that users are able to propose alternative methodologies if they can demonstrate evidence of variations, account for any impact this may have on default factors already used and sensitivity test appropriately.

3.2.3 Subsection 2.2: Benefits

This introductory section discusses techniques for assessing benefits of transport projects; however, there is no specific reference to assessing benefits of ITS projects.

Section 2.3 of the EEM sets out the three types of benefits that can accrue to transport activities:

- *Benefits with monetary values derived from the marketplace, eg vehicle operating costs and the value of work travel time.*
- *Benefits that have been given a standard monetary value, although sometimes these are expressed as the equivalent in vehicle time saving, eg real-time information signs*
- *Benefits that have not been given a standard monetary value, either because it is inappropriate or it has not been possible to establish a standard value, eg cultural, visual or ecological impact*

The EEM provides market–based monetary values for the major land transport benefits and appendix A8 provides standard monetary values for several external impacts.

The EEM notes there are various techniques that allow economic values to be assigned to benefits, eg willingness to pay, avoidance or mitigation costs, and that where benefits not assigned monetary values in the manual are likely to be significant, it may be desirable to undertake such an analysis. The EEM states that where no monetary value is available, the benefits should be described and where possible quantified, and also reported as an input to the Transport Agency's funding allocation process.

Table 3.1 shows the types of benefits associated with each type of activity. The benefits listed under transport demand management (TDM) and education/marketing show the most alignment with the types of benefits associated with ITS found in the literature review. A separate column for ITS has been added to the table to make the particular benefits associated with ITS much clearer.

Table 3.1 Types of benefits by activity used in economic evaluation in the EEM and ITS benefit types

Benefit type	Road	Transport demand management	Transport services	Walking and cycling	Education promotion and marketing	Parking and land use	Private sector financing and road	ITS benefits
Travel time cost savings	✓	✓	✓	✓	✓			✓
Vehicle operating cost savings	✓	✓	✓	✓	✓			✓
Crash cost savings	✓	✓		✓	✓	✓		✓
Seal extension benefits	✓							
Driver frustration reduction benefits	✓							
Risk reduction benefits	✓	✓	✓		✓		✓	✓
Vehicle emission reduction benefits	✓					✓		✓
Other external benefits	✓	✓	✓	✓	✓	✓	✓	✓
Mode change benefits		✓	✓	✓	✓			✓
Walking and cycling health benefits		✓		✓				
Walking and cycling cost savings		✓		✓	✓			
Transport service user benefits			✓			✓		✓
Parking user cost savings		✓			✓	✓		✓
Journey time reliability benefits	✓	✓	✓	✓				✓
Wider economic benefits	✓		✓					
National strategic factors	✓	✓	✓		✓			

More detailed descriptions of the types of activities covered is provided in subsequent sections of the EEM. However the sections which are applicable to ITS are not clearly described.

For example, section 4.3 describes the specific procedures to be used to evaluate the economic efficiency of TDM activities, which may involve:

> *infrastructure, education, promotion and marketing, policing, work/study place policies, new transport services or service improvements, pricing and financial incentives, parking management, and land use design/management.*

However ITS is not specifically listed.

A reference is given in the TDM section of the EEM to the Victoria Transport Policy Institute *Online TDM encyclopaedia* (www.vtpi.org/tdm/tdm12.htm). This reference lists ITS as a possible TDM intervention to reduce congestion; however, the EEM needs to be clearer that the EEM TDM procedures can be used for types of ITS. For example signs giving travellers expected journey times on given routes affect transport demand and therefore could be evaluated with this procedure.

Similarly, section 4.6 'Evaluation of education, promotion and marketing' describes specific procedures to be used to evaluate the economic efficiency of education, promotion and marketing activities including travel behaviour change, road safety promotion, and other education, promotion and marketing-based TDM programmes. Thus ITS activities that provide information signs which change behaviour, such as general safety messages delivered to car drivers using VMS, could be evaluated using the procedures in this section.

In summary it appears that ITS could be evaluated using a number of procedures in the EEM but it is not clear which specific procedures should be used. A separate section on the evaluation of ITS benefits would make it much clearer. This section should address the ITS benefits not covered by the manual such as traveller satisfaction benefits over and above existing benefits covered in the manual.

3.2.4 Subsection A3.19: Bottleneck delay

This procedure produces the average delay per vehicle during an incident. It can be used to calculate the benefits of reducing the duration of the incident, as could be the case with an incident and management system in place. The procedure requires three inputs: traffic volume, road capacity and the duration of the incident. The reduction of the duration of the incident has to be assessed on the basis of the historical record. Some studies indicate that early detection and management of incidents can reduce the duration of an incident by 40% to 60%.

3.2.5 Subsection A3.21: Additional travel time resulting from speed change

At times, for traffic management purposes, lane speed signs may instruct the drivers to reduce their travel speed. This would imply the reduction of speed and then acceleration to the original speed. This procedure allows the additional travel time resulting from speed change cycles to be determined.

3.2.6 Section A4: Travel time

Travel time cost savings analysis is covered in this section of the EEM. The unit travel time values are provided in dollars per hour for travellers split into travel purpose, for vehicle and freight time, and for road category and time of the day. This material is sufficient for evaluation of travel time savings achieved by various ITS measures, such as advanced signal control, ramp metering, parking management or traffic signal pre-emption.

The details of two procedures dealing with specific aspects of travel time (traffic congestion and trip time reliability) are described below.

3.2.7 Subsection A4.4: Traffic congestion

The EEM stipulates that road users value relief from congestion above their value of travel time saving. Since one of the outcomes of the ITS installation is congestion relief, this procedure is useful for the assessment of the benefits of the decongestion. The inputs to the procedure are traffic volume, road capacity, duration of the period of congestion and the congestion unit cost (increment for congestion). The maximum increments for congestion (CRV in $/h) are provided in the manual.

3.2.8 Subsection A4.5: Improved trip time reliability

One of the benefits of the application of ITS is improved trip time reliability. It applies mainly to bus transport whose efficiency can be improved by a number of measures, such as signal pre-emption or vehicle location and dispatch systems. The reported studies show a 5% improvement in on-time arrivals due to the vehicle location and dispatch systems a 35% reliability increase or reduction of travel time variability in the range of 30% to 60% due to traffic signal pre-emption.

But personal travel by any mode also benefits. The benefits reported in the literature show an improvement in journey time reliability due to pre-trip information ranging from 5% to 15%.

The procedure requires the calculation of the standard deviation of the existing travel time and of the benefits on the basis of the assumed improvement of the variability. The EEM provides the co-efficients and monetary values required to calculate the benefits. The output of the analysis is the variability benefit expressed in dollars per hour.

3.2.9 Section A5: Vehicle operating costs

The benefits of vehicle operating cost savings, which largely comprise reduced fuel usage, are extensively covered in this section of the EEM. Vehicle operating costs are wider than fuel usage, and also cover repairs and maintenance. Various ITS measures aim at reducing fuel usage costs by affecting speed change cycles, congestion or making the trips shorter.

The EEM provides the unit vehicle operating costs in cents per kilometre for various vehicle classes for a full range of operating speeds and road types. It also covers the speed change cycles and congestion. It is a comprehensive coverage of the vehicle operating costs, which is sufficient for the evaluation of fuel usage savings associated with ITS outcomes.

3.2.10 Section A6: Crash costs

This section of the manual comprehensively covers the crash analysis and the cost savings achieved by crash reduction. Various ITS measures aim at reducing the number of crashes or crash severity. Integrated traveller information systems in Europe have been reported to reduce fatal crashes by 3% and injury crashes by 2%. Incident detection and management can reduce the number of secondary rear-end crashes by 40%. Ramp metering is also effective, reducing the number of merging crashes by between 30% and 50%.

The EEM provides different methods for calculating crash costs at a site. The choice of method depends on:

- the nature of the site (eg average annual daily traffic length)
- the availability of a reliable crash history for at least five years
- the availability of suitable crash prediction models or exposure-based crash prediction equations
- whether the option will result in a fundamental change in the site.

The EEM’s coverage of crash costs is sufficient for the evaluation of ITS outcomes.

3.2.11 Section A9: Vehicle emission

The EEM comprehensively covers vehicle emissions. The emissions procedure estimates the produced amounts (in g/veh-km) of carbon monoxide, nitrogen oxides, particulate matter and volatile organic compounds. The inputs to the procedure are traffic volumes, vehicle flow composition and traffic speed. The coefficients for the formulae are provided.

A separate procedure is provided for the estimation of the cost of emitted carbon dioxide.

Generally the amount of emissions is related to travel time (especially if vehicles are stationary and idling) and distance. Various ITS measures reduce these aspects, therefore reducing the amount of emissions and fuel use (fuel use is addressed through vehicle operating cost savings). The manual's coverage of vehicle emissions is sufficient for the evaluation of ITS outcomes.

3.2.12 Sections A15 and A18: Public transport costs and user benefits

One of the important aspects of ITS applications is improvement of the quality of public transport service. The reported benefits include the following examples: reduced delay at the intersections, reduced number of stops on the route, improved travel time reliability, environmental improvements, travel time savings (from reduced number of stops end-route) and increased passenger satisfaction.

The EEM provides procedures to quantify and value the benefits of activities arising from, for example, increased service frequency, improvement of travel time reliability, a reduction in transfer time, improved travel comfort on board or infrastructure features at the bus stops.

In order to convert the attributes into monetary values, the EEM uses factors based on research by others. A reference to Australian practice is provided (ATC 2006) and willingness-to-pay values derived from stated preference surveys are mentioned. Such conversion factors are used as the equivalent time to a minute late ratio or in-vehicle time (IVT) equivalents expressed in minutes.

In their report on the economics of public transport Wallis et al (2013) reviewed the international research on IVT and found room for improvement. The values they quoted from various sources were dispersed in wide ranges. Their report contained comments such as 'We note there is some lack of clarity as to the interpretation of this table and the accompanying text' or 'This traditional assumption dates back to the 1970s. Most of the more recent studies have found lower factors'.

As far as ITS applications are concerned the EEM provides IVT valuation for real-time bus arrival time displays at the bus stops only. Wallis et al (2013) indicate that the IVT values should be updated. The evaluation therefore should be subjected to sensitivity testing as required elsewhere in the EEM.

3.3 ITS functionalities which require additional procedures for assessment

The second group of ITS functionalities does not physically alter the transport network but provides information to the traveller to help them select the most appropriate route for their trip or the best time to start the trip or the most appropriate mode.

There are a few aspects of traveller information that make the uptake/use of traveller information difficult to assess/evaluate using the EEM. The first is whether the traveller receives the information, the second is if they act on the received information, and the third is whether they derive the expected benefits. Due to the lack of detailed procedures, inexperienced evaluators, in particular, cannot easily evaluate the provision of traveller information, irrespective of the technology employed. As noted above, once the travel time savings, crash cost reductions and other traditional benefits resulting from traveller information have been quantified, they can be assessed using the relevant procedures in the EEM. For example where information leads to mode change or travel time change the use of the travel behaviour change procedures may be applicable. However, there are gaps in the manual covering quantification of the effects of traveller information on travel time etc and also on the value that users place on this information.

Therefore a methodology needs to be developed to more easily assess the impacts of the information provided to travellers pre-trip or end-route, and to express the benefits in monetary terms.

Examples of ITS information technologies include:

- *Dissemination of pre-trip travel information* is mainly done by websites, telephone dial-in, radio HAR, commercial radio, mobile telephone apps and telephone text messages.
- *Dissemination of end-route travel information* is done by VMS, mobile telephone app, telephone text messages, radio HAR, real-time passenger information at bus stops, passenger information on board, parking information.

4 Existing ITS evaluation procedures

Very little material on the topic of attaching monetised values to customer satisfaction arising from traveller information was revealed in the international literature. Most of the studies considered in the review focus on traveller satisfaction surveys with the information provided or the technology used to provide it. A commonly expressed opinion in the studies is that the evaluation of ITS projects is complicated by the presence of the unique variables. In addition the studies often stated that ITS benefits such as user satisfaction and comfort, improved availability or quality of information are difficult to quantify, although the EEM does provide values for driver and passenger comfort in cars and on public transport, and willingness to pay has been used to value real-time information.

The Transport Agency position statement on ITS (NZ Transport Agency 2014c) notes additional factors, both favourable and unfavourable, that need to be considered and which may involve benefits not currently counted:

- Simplification of combined and shared information provides better services and a reduction in customer effort.
- Customer satisfaction would be improved by such actions as better access to information, or faster response to enquiries.
- Increased confidence in accessing services or networks.
- The greater transparency provided by real-time information might increase accountability for service providers, and so might improve services.
- Over-reliance on technology, which is a risk since technologies sometimes fail.
- Potential invasion of privacy.

Nevertheless, we consider the case for the presence of unique variables associated with ITS benefits needs further research before it can be accepted. If one asks the question 'why is the customer satisfied?' one may find the benefits that contributed to the satisfaction are already counted, and hence user satisfaction would be double counting benefits. It needs to be proven that double counting will not occur.

It is important that the evaluation of the technology concerned includes rigorous sensitivity testing and does not imply false precision to the estimated impacts. The ITS evaluation methodology must allow comparison of ITS projects with non-ITS projects. The EEM already covers this adequately.

In conclusion, the international literature review and review of the EEM have confirmed the gap in existing ITS evaluation methodologies. Recommendations for the development of methodologies and further research and work to fill this gap are given in chapter 5.

5 Development of methodologies and further research to close the gap

5.1 Methodologies

Possible techniques for quantifying ITS benefits are discussed below.

5.1.1 Willingness to pay

In the context of this research, willingness to pay is the maximum amount an individual is willing to pay for the proposed service. This amount is based on the qualitative assessment of the value of the service. Typically, the bus passenger would be asked how much more they would be prepared to pay for the bus ticket if the real-time bus arrival information was provided at the bus stops. The reply would give an indication of the monetary value of the installation of real-time information panels at bus stops.

5.1.2 Willingness to accept

Willingness to accept is the amount of money an individual is willing to accept as a compensation for abandoning a service or lowering its quality. A typical example would be the willingness to accept a certain level of air pollution for a monetary compensation, such as a reduction in the amount of municipal rates. As noted in Guria et al (2005) psychologists have shown that people often treat gains and losses asymmetrically and tend to require a substantially larger increase in wealth to compensate for a loss than the amount they would be willing to pay for an equivalent gain.

5.1.3 Nominal group technique

The nominal group technique is a process involving a group of individuals who would rate the various attributes of the project. It can be used in groups of many sizes, who want to make their decision quickly but want everyone's opinions taken into account.

First, every member of the group gives their rating with a short explanation. Then, duplicate solutions are eliminated from the list of all solutions and the members proceed to rank the attributes. There are variations on how this technique is used. For example, it can identify strengths versus areas in need of development, rather than be used as a decision-making voting alternative. Also, the attributes do not always have to be ranked, but may be evaluated more subjectively.

This technique is considered appropriate because it does not rely on the experts but values the opinions of all group members.

5.1.4 Delphi method

The Delphi method is a structured communication technique, which relies on a panel of experts. The experts answer questionnaires in several rounds. After each round a facilitator provides an anonymous summary of the experts' rating of the various attributes. Then experts are encouraged to revise their earlier answers in light of the replies of other members of their panel.

It is believed that during this process the range of the answers will decrease and the group will converge towards the compromise answer. The process is stopped after an achievement of consensus.

Delphi is based on the principle that decisions from a structured group of individuals are more accurate than those from unstructured groups. However, it is considered to be less suitable for the purpose of the evaluation of ITS attributes, because it relies on the opinions of experts rather than of the general public.

5.1.5 Stated preference surveys

Stated preference (SP) survey is a type of consumer preference survey where individuals are asked how they would respond to various situations. Two techniques used in SP analyses are contingent valuation and conjoint analysis. Contingent valuation (attitudinal) surveys ask respondents directly how they would respond to various situations, or asks them to rate or rank their preferences for various levels of service, facility or situation.

This often gives values several times higher than what they would be in reality because people often do not do what they say they would do. This type of survey tends to be better suited to evaluating relative preferences and for estimating the maximum possible response to an action, than to predicting actual changes in travel.

Conjoint analysis (hypothetical choice) surveys require respondents to make choices between hypothetical alternatives with varying attributes. It is necessary to have forced trade-offs so that a better environment might be coupled with higher costs or a higher travel time. This forces the respondent to relate the value of each component of preference.

SP surveys need to be stratified by audience: current users versus potential users. Current users should be asked to respond to questions about factors that would provide for a more comfortable or attractive journey through different types of environments, facilities or levels of service. For potential users, it is important to create scenarios based on constructed markets.

SP surveys are an appropriate tool for evaluation of non-measurable aspects of ITS applications as well as for comparison of the measurable outputs of ITS with non-measurable aspects.

5.1.6 Revealed preference surveys

Revealed preference (RP) survey is another type of consumer preference survey. RP surveys observe actual behaviour under varying conditions, for example the modes of travel used by household members relative to the level of service of public transport. This information is then analysed to identify and quantify the factors that influence travel decisions.

In terms of ITS evaluation RP surveys are less applicable than SP surveys, because they are limited to the existing applications and cannot be used to assess hypothetical situations.

Further work is needed to establish the nest methodologies for assessing ITS benefits, for example whether willingness to accept is a more appropriate methodology for accurately assessing ITS benefits.

6 Conclusions and recommendations

6.1 Conclusions

A review of the international literature brought information about the benefits of the ITS applications as well as their potential drawbacks, and the methodologies used to assess the benefits of the aspects which cannot be quantified, such as provision of information to travellers and transport authorities. The literature review found many examples of literature providing information on the benefits of ITS both qualitative and quantitative. However, very little material was found on specific methodologies comparing the value of monetised user benefits from ITS elements, such as real-time information display at bus stops, with the monetised benefits from infrastructure improvements, such as travel time saving.

A review of the Transport Agency EEM identified procedures that can be used to the evaluation of ITS applications. However, there are ITS aspects which cannot be satisfactorily assessed by the EEM procedures and further work into these areas is recommended

In conclusion, the international literature review and review of the EEM have confirmed there are major gaps in existing ITS evaluation methodologies and further work into these areas is recommended.

6.2 Recommendations

The following topics have been identified in the course of this work as the areas where further applied research is recommended.

- **Topic 1**. The EEM provides the methodology for the assessment of the cost of the bottleneck delay. This methodology can be used for assessment of the efficiency of ITS incident detection and management. The three inputs required are traffic volume, road capacity and the duration of the incident. The first two inputs are readily available. The third input, the duration of the incident, has to be assumed.

  Overseas sources indicate that the early detection and management of incidents can reduce the duration of an incident by 40% to 60%. There is a lack of local data on the duration of incidents, especially for the strategic infrastructure, such as Auckland Harbour Bridge.

- **Topic 2**. The literature sources claim that the information conveyed by VMS can result in a travel time saving of up to 20%; this aspect could be investigated. There is no local data, although this is an important input for the evaluation of the benefits of a VMS installation.

- **Topic 3**. The value quoted in the references of the average delay reduction at intersections due to traffic signal pre-emption is five seconds per bus per intersection. This is an important input for the evaluation of the efficiency of the signal pre-emption for buses at intersections and as such local research data would be beneficial for future ITS project evaluations.

- **Topic 4**. Various ITS applications, such as traffic signal pre-emption, vehicle location and dispatch systems or pre-trip information can improve the bus trip time reliability. There is a range of values quoted in the literature, from a 5% reliability improvement due to pre-trip information to up to 60% improvement due to traffic signal pre-emption.

  Local research on the sources of the trip time reliability improvements and the magnitude of the benefits due to each source would be useful for the evaluation of ITS projects.

- **Topic 5**.The EEM comprehensively covers the crash analysis and the cost savings achieved by crash reduction. Various ITS measures, such as integrated traveller information, ramp metering or incident management aim at reducing the number of crashes or crash severity. Nevertheless, the magnitude of crash reduction is not well determined. The values in the literature range from 2% injury reduction due to traveller information to 50% reduction of merging crashes due to ramp signalisation.

  Local research on the sources of the crash reduction, the type of crash affected and the magnitude of the reduction associated with each source would greatly contribute to the evaluation of ITS projects.

- **Topic 6**. Commuter surveys conducted overseas showed that up to 60% used the travel information websites to obtain pre-trip information. Many of them confirmed they found the information useful, and a high proportion of respondents stated they used the information to good effect.

  With smart phones and apps commonplace today it might be expected that more travellers obtain pre-trip information. An investigation could be conducted to identify which of the pre-trip information sources are most popular, the quality of the information and how many travellers would use this information for planning their trips. The investigation could be extended to the end route information. These figures would be invaluable for the assessment of ITS projects.

In addition to the above applied research, pure research is recommended to address the gap in the economic theory underpinning ITS benefits, for example, whether willingness to pay or willingness to accept is the appropriate methodology for assessing ITS benefits.

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Appendix A: Glossary

ACEA	European Automobile Manufacturers' Association
ALPR	automatic licence plate recognition
APMS	advanced parking management system
ATC	Australian Transport Council
ATIS	advanced traveller information system
ATMS	advanced transportation management system
ATP	automatic train protection system
AVL	automatic vehicle location
BART	Bay Area Rapid Transport
BCR	benefit–cost ratio
BITRE	Bureau of Infrastructure, Transport and Regional Economics (Australia)
CCTV	closed circuit television
CMS	changeable message signs
CRV	incremental value for traffic congestion
DfT	Department for Transport (UK)
DOT	Department of Transportation (US)
DSRC	Dedicated Short Range Communications
EEM	Economic Evaluation Manual (NZ Transport Agency 2013)
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
FHWA	Federal Highway Administration (US)
FY	financial year
GAO	Government Accountability Office (US)
GPS	Government Policy Statement on Land Transport or global positioning system
HAR	highway advisory radio
ICT	information and communication technologies
IDAS	ITS Deployment Analysis Software
IPENZ	Institution of Professional Engineers New Zealand
IRF	International Road Federation
ITS	intelligent transport systems
IVT	in-vehicle time
MIDAS	motorway incident detection and automatic signalling
MoT	Ministry of Transport
NO_x	nitrogenoxides
NGT	nominal group technique
NZIER	New Zealand Institute of Economic Research
OAG	Office of Auditor -General

ODOT	Oregon Department of Transportation
P2P	point to point (speed enforcement)
PSAP	public service answering point
RIS	river information services
RDS	radio data system
RP	revealed preference
SAEJ	Society of Automotive Engineers of Japan
SDE	speed over distance enforcement
SESAR	single European sky ATM (air traffic management) research
SP	stated preference
TDM	transport demand management
TEN-T	Trans-European Transport Networks
TMC	traffic message channel
TRL	Transport Research Laboratories
TSP	transit (public transport) signal priority
veh/h	vehicles per hour
VICS	vehicle information and communication system
VKT	vehicle-kilometrestravelled
VMS	variable message sign