THE EFFECTS OF INTELLIGENT TRANSPORT SYSTEMS ON CO_2 EMISSIONS - AN AUSTRALIA PERSPECTIVE

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Abstract

Apart from during the global financial crisis the Australian road sector has seen strong growth in CO_2 emissions: 34% between 1990 and 2010. The Garnaut Reviews explored a number of emission-reduction options, but largely overlooked the application of information and communication technology (ICT) to road transport - referred to as intelligent transport systems (ITS). ITS is an umbrella term for applications which improve the efficiency, safety and environmental performance of transport. Rapid developments in ICT have led to the realisation of several ITS concepts. Research and policy activity has grown accordingly, especially in Europe, the US and Japan. Future ITS investment decisions in Australia will require an understanding of which applications are the most effective at reducing CO_2 emissions, and in which context they will have the most benefit. There are, however, no accepted frameworks or tools for evaluating the impacts of ITS on emissions. This paper considers the state of ITS in Australia and reviews its effect on emissions. Some methodological challenges are discussed. The paper then describes a new software tool - the power-delta-power (PΔP) model - which is well-suited to evaluating the effects of some types of ITS on emissions from Australian vehicles. An example is provided to demonstrate the capabilities of the model.

Keywords: intelligent, transport, emissions, traffic management

1. Introduction

Australia generates only 1.5% of global greenhouse gases (GHGs) but its *per capita* emission, at 28 tonnes of CO_2-equivalent (CO_2-e) in 2006, is amongst the world's highest (DCC 2008). The main reason for this is Australia's carbon-intensive electricity sector but, as in other developed countries, road transport is also a major emitter. According to the Government's submission to the United Nations Framework Convention on Climate Change (UNFCCC), in 2010 road transport generated 71.5 Mt of CO_2-e, equating to 13% of Australia's total and 86% of emissions from all transport (DCCEE 2012).

The transport sector is also a strong source of emissions growth. Figure 1 compares CO_2 emissions from road transport in Australia, the US, the EU-27 and Japan. Emissions in the four regions increased by 20% between 1990 and 2000, but by 2010 emissions in Japan had almost returned to 1990 levels as a result of more efficient freight transport, improved fuel economy, increased use of 'micro' and hybrid cars, and reduced congestion (OECD ITF 2009). Emissions in the US and the EU-27 continued to increase until checked by the economic crisis of 2008.

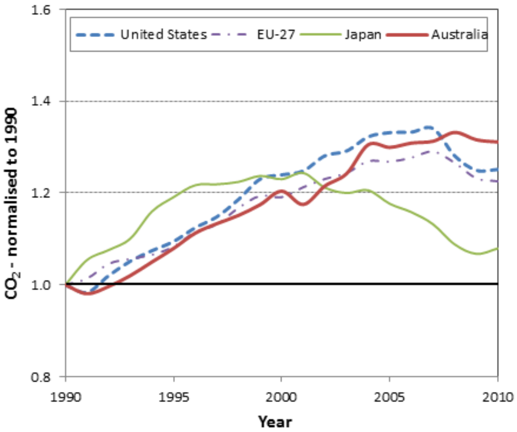

Figure 1. CO_2 emissions from road transport from 1990 to 2010, normalised to 1990 (UNFCCC).

Australia weathered the crisis better than other developed countries, and the reduction in emissions after 2008 was less pronounced. CO_2-e emissions from Australian road transport were 34% higher in 2010 than in 1990 (DCCEE 2012). The Climate

Change Reviews concluded that unless action is taken Australian transport emissions are likely to grow further in the future (Garnaut 2008, 2011).

Whilst Garnaut explored a number of GHG-reduction options, one area that was largely overlooked is the use of information and communication technology (ICT) in road transport - referred to as intelligent transport systems (ITS). ITS is an umbrella term for applications which improve the efficiency, safety and environmental performance of transport. In the late 1990s ITS generated considerable enthusiasm for these reasons (USEPA 1998). Recent developments in ICT have led to the realisation of several ITS concepts, and research and policy activity has increased significantly in Europe, the US and Japan (e.g. European Commission 2009; USDOT 2011). ITS is now viewed as an important element of any integrated GHG-reduction strategy.

Benz *et al.* (2011) noted that future ITS investment decisions will require an understanding of which applications are the most effective at reducing CO_2 emissions (and other air pollutants), and in which context they will have the most benefit. There are, however, no accepted frameworks or tools in Australia (or indeed elsewhere) for evaluating the impacts of ITS on GHG emissions.

2. ITS in Australia

Significant work on ITS (architecture, standards, opportunities in road safety and freight, etc.) has been undertaken by Austroads (2007; 2010a; 2010b; 2011). The environmental potential of ITS is recognised in the recent ITS Policy Framework (SCOTI, 2012), and more explicitly in an Industry Strategy which promotes environmental protection as one of three core 'pillars' (the others being safety and mobility) (ITS Australia 2012).

There is a large and diverse array of ITS applications and services, and ISO Technical Committee 204 has developed a standard (though rather detailed) nomenclature. In this paper we refer, with some slight changes, to the simpler 'focus areas' of ITS Australia (Table 1). One area that is not stated in Table 1, because of its cross-cutting nature, is cooperative systems. These involve communication from vehicle to vehicle ('V2V') or between vehicles and infrastructure ('V2I'), and use sensors to gather information on the driving environment, including road and weather conditions, traffic behaviour and vehicle trajectories. The information fed back to drivers allows them to respond to any changes (Spence et al. 2009).

Some ITS systems are well-established in Australia. For example, since the 1960s the implementation of UTC in major cities has mirrored that in Europe and the US. This has been followed by, amongst other things, traffic responsive systems, ramp metering, incident detection, VSLs and VMSs. However, Nelson and Mulley (2012) observed that Australian cities have a relatively low incidence of the use of ITS in public transport.

Table 1: Focus areas for Australian ITS Industry Strategy (adapted from ITS Australia 2012).

ITS category		**Example(s)**
1.	Advanced traffic and transport management	Managed motorways, ramp metering, variable speed limits (VSLs), variable message signs (VMSs)
		Slot management
		Platooning
		Urban traffic control (UTC), such as traffic-adaptive signals, 'green waves', public transport priority
		Parking management
2.	Vehicle detection and enforcement	Electronic tolling systems to support road user charging
		Traffic enforcement
		Demand/access management (restricted traffic zones, low emission zones, etc.)
3.	Passive driver information	Gear-shift indicators
		Lane departure warnings
		On-board navigation
4.	Active driver assisstance solutions	Predictive terrain adaptive cruise control
		Pedestrian avoidance
		Adaptive cruise control (ACC), intelligent speed adaptation (ISA)
		Vehicle & infrastructure-based accident prevention
		Automatic/intelligent parking
		Lane-departure warnings, collision-avoidance systems.
5.	Traveller information systems	Web-based pre-trip information and route planning
		Eco-routing advice
6.	Vehicle performance tracking and monitoring	In-vehicle logging
		Commercial fleet management
		e-freight
		Demand-responsive public transport
		Loading/delivery management
7.	Environmental solutions	Managed charging of electric vehicles

Some recent ITS developments in Australia include:

- Managed motorways
- Coordinated freeway ramp signals on the M1 in Melbourne
- Free-flow electronic tolling (NSW GMR)
- Area-wide UTC: SCATS, TRAC, STREAMS, etc.
- Public Transport Information and Priority System (PTIPS), which merges a bus priority system with on-board data collection and transmission systems and SCATS
- Web-based trip planning tools, including *131500* in Sydney, Public Transport Victoria *Journey Planner* and *Translink* in South-East Queensland
- Incident detection systems (e.g. Melbourne)

- South Australia trial of cooperative systems
- Gold Coast rapid transit project
- Vehicle activated signs
- Intelligent speed assistance (NSW & WA)

Various technologies are currently undergoing trials.

3. Studies in the literature

The effects of various ITS applications on CO_2 emissions or fuel consumption (FC) are summarised in Appendix A. These applications vary in size and scope, reflecting the diverse nature of ITS and the mechanisms by which it can influence emissions. The results suggest that reductions in emissions of up to around 20% are typically possible through ITS, although some studies include effects on traffic volume whereas others give results per vehicle.

In a wide-ranging study Klunder et al. (2009) estimated the potential CO_2 reductions for various ITS measures in the EU. Measures having a 'very large' CO_2 reduction were eco-driving coaching and assistance (e.g. gear-shift indicator, speed profile advice). 'Pay-as-you-drive' and platooning were found to give a 'large' CO_2 reduction. Measures with a 'medium' CO_2 reduction included ACC, dynamic traffic light synchronization, fuel-efficient route choice, and automatic engine shutdown.

Congestion charging (with ITS) has led to significant reductions in emissions in London (TfL 2008) and Stockholm (Johansson et al. 2009). However, such schemes have a lower overall CO_2-reduction potential because they are restricted to certain situations (large cities and main transport corridors).

There have been relatively few studies in Australia. Chong-White et al. (2011) investigated the potential benefits of SCATS, but did not present detailed results for emissions. Smit et al. (2010) examined the impacts of eco-driving for the Australian situation, and concluded that CO_2 benefits reported in overseas literature should not be directly applied to Australia with caution. For instance, the high proportion of larger engines in Australia increases the potential FC benefits of eco-driving, but the large share of cars with automatic transmission means that attempts to change gear-shift behaviour are generally less relevant. The promotion of other advice (e.g. smooth driving, avoiding stops, less severe accelerations) would be more appropriate. Eco-driving can also increase emissions under certain conditions. Vermeulen (2006) measured an increase of 30% in NO_x emissions from diesel cars in urban driving when eco-driving advice was applied. As NO_x is a critical air pollutant this is not a trivial issue, particularly in Europe, but also in Australia where diesel cars make up an increasing proportion of the fleet.

4. Methodological challenges

ITS operates on various spatial and temporal scales, and can affect demand for transport, modal split, the distribution of vehicles on the network, and driving behaviour. The effects are also dynamic, incorporating real-time information and behavioural choices (Benz et al. 2011). Impacts on CO_2 can be broadly divided into those that are direct (reduced demand, higher infrastructure efficiency, higher vehicle efficiency) and those that are indirect (induced demand, reduced congestion due to fewer and less severe accidents). Clearly there are interactions (e.g. driving dynamics are dependent of congestion), and any given measure can have a complex pattern of multiple effects. The mechanisms by which ITS applications can influence emissions are summarised in Appendix B.

To estimate the impact of a given application on CO_2 emissions a chain of models/information is needed (Klunder et al. 2009). Figure 2 shows simplified examples of how ITS can influence traffic characteristics, and how 'macro-scale' (region/ network traffic level), 'meso-scale' (road traffic level), 'micro-scale' (vehicle level) models are relevant to assessments.

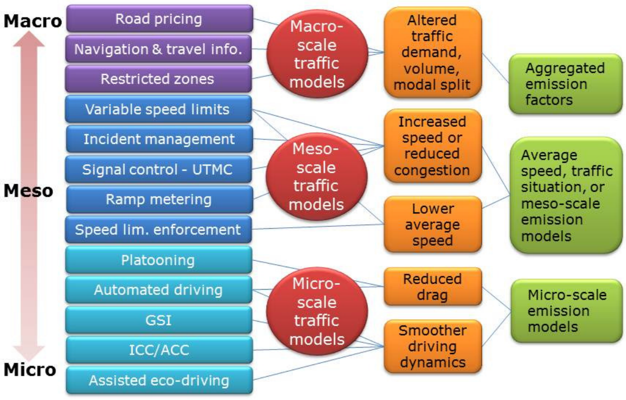

Figure 2: Examples of ITS applications and assessment models.

Where an application leads to an overall change in demand the main factor affecting CO_2 emissions is likely to be the reduction in VKT; driving behaviour may not be significantly affected, and therefore macro-scale models and 'aggregated' emission factors can be used. Where there is a spatial re-distribution of traffic, with changes in the volume, composition and speed on different roads, and a need for a more detailed assessment, a meso-scale traffic model and an 'average-speed' emission model could be appropriate. For the most detailed simulation, involving changes in driving dynamics, micro-scale traffic and emission models are needed, ideally with a simulation of 'instantaneous' engine power demand (Klunder et al. 2009).

However, the selection of suitable models for evaluating a given application depends upon several factors, including the ITS mechanism, where it is being introduced, its scale, model capabilities, the required accuracy, the cost and the availability of input data. Concerning the last two item, thanks to developments in ITS more information is becoming available at lower cost, and micro-scale models can now be used for quite large networks. An interesting development is the so-called 'reference model' approach, which attempts to understand the various processes involved when an ITS application is introduced (Horiguchi et al. 2010), thus assisting model selection.

A potential shortcoming of existing traffic and emission models is that they are based on principles, relationships and data which have been developed and validated under 'traditional' traffic conditions, and not ITS situations. There are also no standard interfaces between models. Moreover, including the effects of ITS on travel demand in models is not straightforward, as it would typically require an understanding of trip motives and mobility over large geographical areas (Benz et al. 2011). Such issues are being addressed in current research projects such as ICT-Emissions (Samaras et al. 2011) and AMITRAN (http://www.amitran.eu/).

5. Emission modelling in Australia

Although Australian State and Federal Departments have developed vehicle emission inventories, until recently there have been no actively maintained models. Whilst established tools are available in Europe and the US (such as COPERT and MOVES), studies have shown that these should reflect the local fleet composition and driving characteristics in order to provide accurate results. As a consequence, new macro- and micro-scale software tools have been developed specifically for Australian conditions.

The macro/meso-scale model - COPERT Australia - is designed to estimate fleet emissions at the country or State level (Smit & Ntziachristos, 2012), but can also be used for small networks. It uses average speed to describe driving behaviour and traffic conditions, providing FC and emissions for 241 vehicle types. The model covers a wide range of pollutants and includes all emission sources ('hot', 'cold start', 'non-exhaust' and 'evaporative').

The micro-scale model - PΔP - is designed for more detailed simulations (Smit, 2013). It uses engine power (P) and the change in engine power (ΔP) to predict FC and emissions (CO_2, NO_x). The model accounts for vehicle type, fuel type (petrol, diesel) and technology level, and includes the most important (73) vehicle classes. The inputs are speed-time data (1 Hz), road grade, vehicle loading and the use of air conditioning. This information is used to compute the required engine power for each second of driving.

6. Evaluation of ITS using PΔP model

The new models can be used to examine the effects of ITS on emissions of GHGs and other pollutants. To illustrate this we used light-duty vehicle (LDV) driving cycles developed for Dutch motorways by Gense et al. (2001). These covered three VSL regimes (80, 100, 120 km/h) and two congestion levels ('free flow' FF and 'more congested' MC), as shown in Figure 3.

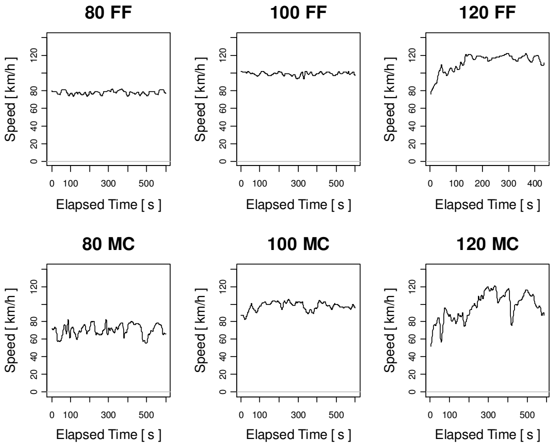

Figure 3. Driving cycles by speed limit and level of congestion.

The cycles were split into around 900 segments, each of length 100 m, and the PΔP model was used to estimate CO_2 emission factors (g/VKT) for the Australian LDV fleet (Figure 4). The COPERT Australia predictions (black line) are also shown. It is clear that PΔP can resolve the variation in emissions due to differences in driving behaviour at a particular average speed, whereas COPERT Australia provides a single value. The segmented emissions were used to compute mean emission factors and 95% confidence intervals (Figure 5).

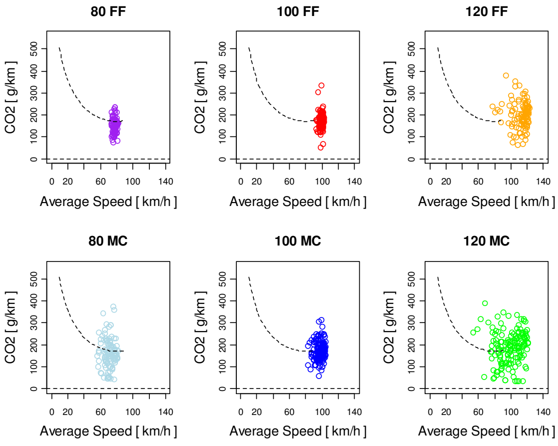

Figure 4. LDV emission factors for CO_2 for different speed limits and traffic conditions.

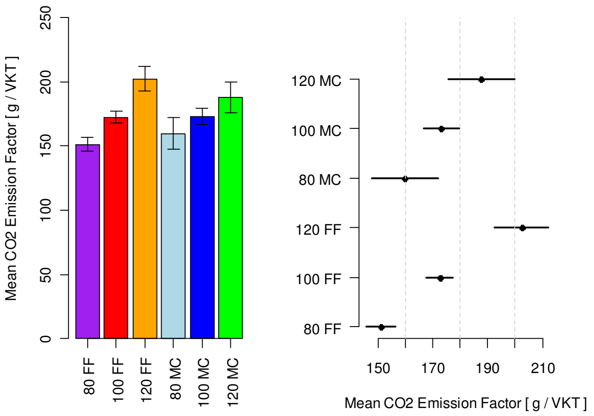

Figure 5. Mean LDV emission factors for CO_2 for different speed limits and traffic conditions, including 95% confidence intervals.

There was a statistically significant ($p<0.05$) increase in CO_2 emissions per VKT of 35% under free-flow conditions when the speed limit was increased from 80 to 120 km/h. Under more congested conditions there was also an increase but the impact was lower (15% from 80 to 120 km/h). An analysis of variance showed that the mean emission factor under congested conditions was significantly different ($p=0.001$), but the Tukey HSD test showed that only the 80 and 120 km/h limits had a significantly different emission factor ($p<0.05$), and that the other combinations (80-100 and 100-120 km/h) were not significantly different.

This example has shown that the Australian emission models can quantify the impacts of ITS measures on emissions per vehicle. The analysis suggests that changes in speed limit can result in significant CO_2 emission benefits for LDVs under free-flow motorway conditions, but that the results are less pronounced for more congested situations.

It is noted that this type of assessment can be extended to include heavy-duty vehicles (trucks, buses) and air pollutants such as NO_x. For a complete assessment of VSLs these emission factors should be combined with traffic models or measured traffic data to estimate the impact on total emission levels across road networks.

7. Conclusions and recommendations

This review and initial modelling work has led to the following conclusions and recommendations:

- Whilst certain ITS applications are well-developed, the overall Australian ITS strategy is still in progress.
- The current strategy places environment as a key pillar, but there are few tools for evaluating the effects of ITS on emissions.
- There is a need to develop a framework for ITS evaluation which is relevant to Australian conditions, and traffic/emission models need to reflect the types of vehicle and behaviour on Australian roads.
- The range of emission models available in Australia is limited, with little use of the micro-scale tools that are required to assess some types of ITS.
- Two new models – COPERT Australia and the P∆P model – are well suited to the evaluation of ITS but do not, as yet, contain data that relate specifically to ITS.
- It would be useful to study the impacts of a range of ITS measures using Australian data and emission models.
- The potential for improved model performance through the incorporation of ITS data should be investigated further.

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Appendix A: Review of international studies

ITS category	ITS application	Reduction in FC/CO_2	Notes	Reference
Advanced traffic and transport management	Active traffic management (ATM) – M42 in the UK. Hard shoulder running and 50 mph speed limit.	4%	Car and lorry instrumented to collect driving patterns on the M42-ATM section. Data used with an emissions model.	Highways Agency (2008)
	Lane keeping	0.1%	For EU-27(a).	Klunder *et al.* (2009)
	Slot management	<0.1%	For EU-27(a).	Klunder *et al.* (2009)
	Platooning	6%	For EU-27(a). Applied to VKT on motorways under free-flow conditions.	Klunder *et al.* (2009)
	UTC - signal coordination. Arterial road with 12 signalized intersections in Graz, Austria.	14%	VISSIM micro-scale traffic simulation model, coupled with an instantaneous emission model (PHEM).	Zallinger *et al.* (2010)
	Dynamic traffic light synchronisation	2%	For EU-27(a).	Klunder *et al.* (2009)
Vehicle detection and enforcement	Road pricing (PAYD)	7%	For EU-27(a).	Klunder *et al.* (2009)
	Congestion charging, London.	16%	Reduction for traffic within the charging zone following the introduction of the scheme.	TfL (2007)
	Congestion charging	0.5%	For EU-27(a).	Klunder *et al.* (2009)
	Road charging. Trial system in Stockholm, consisting of extended public transport, a congestion tax, and more park-and-ride sites.	13% in inner city, 3% in metropolitan area	The reductions were mainly due to decreased traffic flow; reduced congestion had little effect.	Johansson *et al.* (2009)
	Enforced speed limits - average speed monitoring scheme on the A13 motorway in Rotterdam.	15%	The speed limit was reduced from 120 km/h to 80 km/h, and enforced via a series of cameras.	EEA (2008)
Passive and active driver assistance	On-board navigation (GPS)	9%	Use of GPS systems to optimise route planning. Including real-time congestion monitoring led to a further 8% reduction in fuel consumption.	Ericsson *et al.* (2006)
	Gear-shift indicators (GSIs)	3-11%	Measurements on 28 passenger cars.	Vermeulen (2006)
		1-6%	Measurements on one vehicle.	Fontaras *et al.* (2008)
	Active speed management	No significant impact	Traffic micro-simulation model in conjunction with an instantaneous emissions model.	Int Panis *et al.* (2006)
	Intelligent speed adaptation	1%	Large ISA trial conducted in Sweden over a three year period. Advisory ISA system.	Swedish National Road Administration (2002)
	Intelligent speed adaptation	37%	Simulation based on a penetration rate of 20%. Effects would be restricted to highly congested conditions.	Servin *et al.* (2006)
	Dynamic eco-driving	10-20%(b)	Advice given in real-time to drivers changing traffic conditions in the vehicle's vicinity. PARAMICS micro-scale traffic simulation tool was applied to the Comprehensive Modal Emissions Model (CMEM).	Barth and Boriboonsomsin (2009)
	Eco-driving assistance	10%	For EU-27(a).	Klunder *et al.* (2009)
	Adaptive cruise control	3%	For EU-27(a).	Klunder *et al.* (2009)
	Eco-driving assistance	10% or lower	Model simulations of a car equipped with employing V2V and V2I technologies.	Kamal *et al.* (2010)
	Intelligent speed control	6% for motorways.	Generalised additive models used. Limited effects for non-motorway roads.	Carslaw *et al.* (2010)
Traveller information	Eco-routing advice	2%	For EU-27(a).	Klunder *et al.* (2009)
Vehicle tracking and monitoring	Trip departure planning (freight)	2%	For EU-27(a).	Klunder *et al.* (2009)
Other	Tyre pressure indicator	1%	For EU-27(a).	Klunder *et al.* (2009)

(a) Includes an assumption of market penetration.
(b) Largest reductions during severely congested conditions. Minimal benefits inder free—flow conditions.

Appendix B: Mechanisms by which ITS applications influence CO$_2$ emissions

ITS category		**Example**	**Main direct impacts on CO$_2$ (●)**			**Indirect effects on CO$_2$**
			Reduction of travel demand (e.g. reduced vkm, increased PT)	**Improving efficiency of infrastructure** (e.g. less congestion, efficient distribution of traffic)	**Improving vehicle efficiency** (e.g. reduced drag, lower driving dynamics)	
1.	Advanced traffic and transport management	Highway ramp metering	-	●	-	Yes(b)
		Variable speed limits	-	●	-	-
		Slot management	-	●	●	-
		Platooning	-	●	●	-
		Urban traffic control	●	●	●	Yes(b)
		Parking management	●	-	-	-
2.	Vehicle detection and enforcement	Road charging, tolls	●	●	-	-
		Demand/access management	●	●	-	-
3.	Passive driver information	Gear-shift indicators	-	-	●	-
		Lane departure warnings	-	-	-	Yes(c)
		On-board navigation	-	●	-	-
4.	Active driver assisstance solutions	ACC, ISA(a)	-	-	●	-
		Pedestrian avoidance	-	-	-	Yes(c)
		Vehicle & infrastructure-based accident prevention	-	-	-	Yes(c)
		Automatic/intelligent parking	-	●	-	-
		Lane-departure warnings, collision-avoidance systems	-	-	-	Yes(c)
5.	Traveller information	Pre-trip information, route planning	●	-	-	-
6.	Vehicle performance tracking and monitoring	Commercial fleet monitoring	-	●	-	-
		e-freight	●	●	-	-
		Demand-responsive PT	●	●	-	-
		Loading/delivery management	-	●	-	-
7.	Environmental solutions	Managed charging of electric vehicles	-	-	●	-

(a) ISA can provide warnings to the driver (advisory ISA), or can be linked to the vehicle's engine management system to provide voluntary (overridable) ISA or mandatory (non-overridable) ISA (Carslaw *et al.*, 2010). ISA can therefore be passive or active.

(b) Possible increase in demand

(c) Less congestion if fewer accidents