Study of Intelligent Transport Systems for reducing CO_2 emissions for passenger cars

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Abstract	This is the report of an internal ERTICO study, supported by ACEA, on the potential contribution of ITS measures to reducing CO_2 emissions for passenger cars. It focuses on in-vehicle applications which use data to build estimation or prediction in order to either guide the driver or control the vehicle in some way, and also on ITS related infrastructure measures which can reduce CO_2 emissions of cars.

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Control sheet

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Executive summary

Objective and scope

This report is the result of an internal study by ERTICO – ITS Europe, supported and funded by ACEA, the European Automobile Manufacturers' Association. The motivation is to support ACEA's CO_2 reduction strategy for post-2020.

ACEA recognises the potential contribution of ITS (Intelligent Transport Systems) to reducing CO_2 emissions, but needs evidence of the impacts of different ITS applications in order to guide further research and development. The ERTICO office has worked on projects related to eco- and energy efficient ITS for many years, as have many members of the ERTICO Partnership (over 100 partners from the private and public sector).

The scope of this study is to assess the contribution of different existing ITS measures to reducing CO_2 emissions of passenger cars with internal combustion engines. These include in-vehicle applications and ITS-related infrastructure measures which can affect the dynamics of driving or road traffic conditions and therefore reduce emissions. Because the study is focused on improving the environmental performance of cars or the ways in which they are driven (and is aimed at guiding research in the automotive sector), it does not cover measures that aim to reduce car use, such as modal shift, teleworking, or suppression of trips by pricing, taxation or access controls.

This report focuses on ITS solutions for which statistical evidence of fuel or CO_2 savings exists: where possible, validated data from trials, supplemented by studies involving driving simulators or modelling. The conclusions then focus on the most promising applications, giving greater detail of expected benefits at a network level.

Overview of key results

The systems covered include in-vehicle applications and infrastructure applications impacting upon vehicles.

Eco-navigation systems are a promising application: indeed navigation systems, some with eco-routing, are already on the market and further improvements to adapt eco-routing to traffic conditions in real-time are in development. The potential for reducing fuel use and therefore emissions is around 10% with real-time eco-routing. This potential of course can be highly variable according to the type network and journeys being made, road topography, traffic conditions, driver's route knowledge, etc.

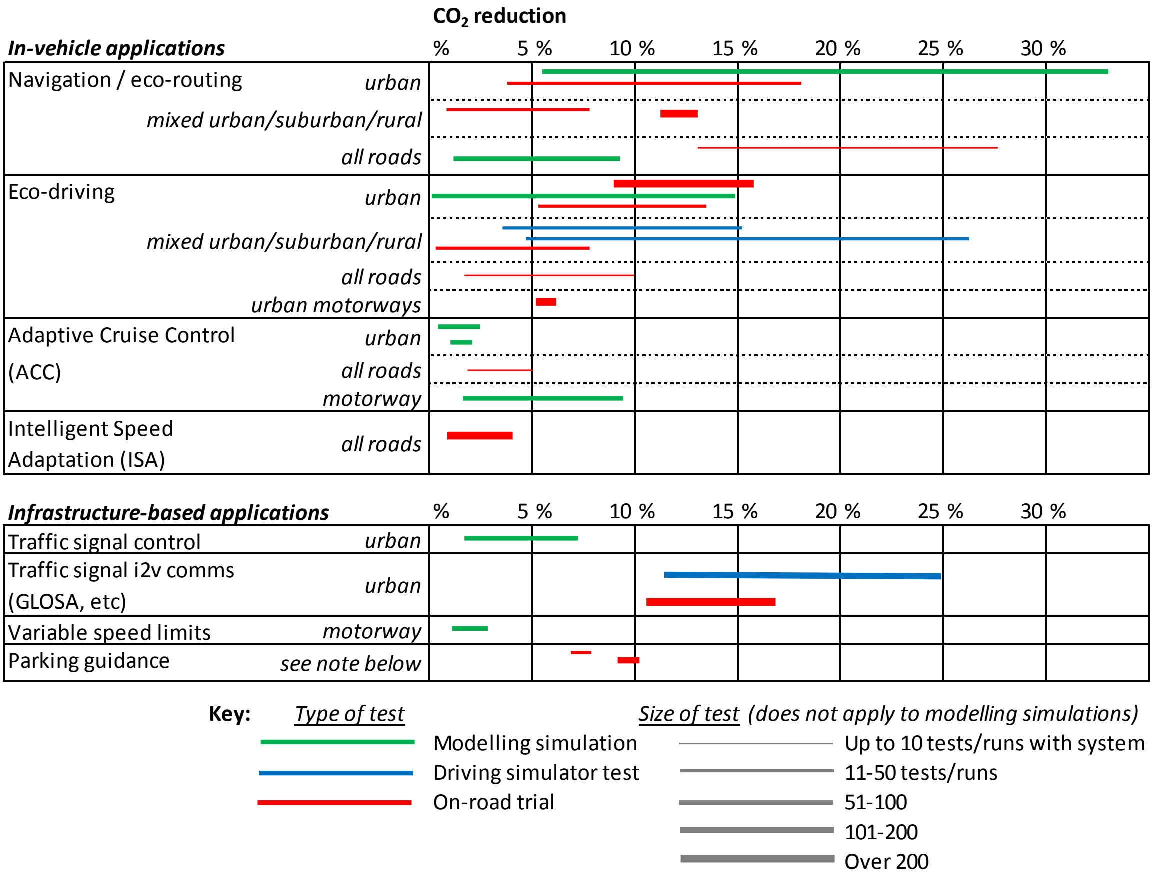
The in-vehicle system offering the greatest potential to reduce emissions is eco-driving. Up to 20% savings are possible, and some cases over 30%. However results are highly variable in terms of context: topography, road type, vehicle type and transmission system, HMI, traffic fluidity, etc. The highest potential tends to be in urban surroundings and especially where there are traffic lights. Integrated eco-routing and eco-driving applications have been developed and tested with very promising results.

Regarding infrastructure, intelligent traffic signal applications can achieve key savings, with results being around 5% for green wave applications. In-vehicle applications provide greater benefits, typically 15-20% but can be up to 25%, although this presents the challenge of creating on-board applications which work with different traffic signal technologies and strategies in different cities and countries.

Intelligent parking can reduce vehicles searching for parking places, thereby reducing traffic (and hence emissions). Reductions of 7 to 10% in distances driven by vehicles looking for a parking space have been recorded, although overall traffic reduction in urban areas cannot be deduced from these results. As for traffic signals, driver information by in-vehicle displays increases the benefits.

Finally, in-vehicle systems like Intelligent Speed Adaptation (ISA) and Adaptive Cruise Control (ACC, including predictive data) can provide small benefits, around 3 to 5%.

The following table provides a snapshot of the potential for CO_2 reduction of the applications studied[1].



[1] This table is given with further explanations including data sources in the Conclusions chapter of the main report. Note that for parking guidance, % reduction applies only to users intending to park.

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Acronym	Description
ACC	Adaptive Cruise Control *Cruise control that slows down and speeds up automatically to keep pace with the vehicle in front. The driver sets the maximum speed (as with standard cruise control), then a radar sensor watches for traffic ahead, locks on to the car in a lane, and instructs the car to stay a certain number of seconds behind this vehicle. ACC is now almost always paired with a pre-crash alert system.*
ACEA	European Automobile Manufacturers' Association
ADAS	Advanced Driver Assistance Systems systems developed to automate/adapt/enhance vehicle systems for safety and better driving. Safety features are designed to avoid collisions and accidents by offering technologies that alert the driver to potential problems, or to avoid collisions by implementing safeguards and taking over control of the vehicle.
ANPR	Automatic Number Plate Recognition
ATCS	Adaptive Traffic signal Control Systems *System to optimise traffic flow by considering traffic flow at multiple sites rather than a single intersection, by enabling traffic signal controlled intersections to interact with each other. They adjust, in real time, signal timings based on the current network traffic conditions, demand, and system capacity.*
C-ACC	Cooperative Adaptive Cruise Control *ACC which includes information transmitted from a vehicle ahead in the same lane (v2v – vehicle to vehicle communications)*
CO_2	Carbon Dioxide
EC	European Commission
	Eco-driving system *Support system designed to influence driver's behaviour: use of gears, engine braking, anticipation, etc. Recognise driving behaviour and provide on-trip advice and post-trip feedback/feed-forward*
	Eco-navigation or Eco-routing *Dynamic navigation which integrates maps with up-to-date traffic information (e.g. RDS-TMC information) and also includes information such as estimated fuel consumption*
EEIS	Energy Efficient Intersection Service
EU	European Union
FCD	Floating Car Data
FCW	Forward Collision Warning
FOT	Field Operational Test

Acronym	Description
GLOSA	Green Light Optimised Speed Advisory *Traffic light phase information transmitted to drivers, together with advice on the best deceleration strategy to approach the intersection at the most energy efficient speed.*
GSI	Gear Shift Indicator
HuD	Head-up Display *A transparent display that presents data without requiring users to look away from their usual viewpoints. Originally developed for military aviation, in this case adapted for cars by displaying information in the windscreen.*
i2v	Infrastructure to Vehicle communications *Note also v2i: vehicle to infrastructure, v2v: vehicle to vehicle, v2x: vehicle to anything*
ICT	Information and Communications Technologies
ISA	Intelligent Speed Adaptation *ISA includes informative systems which warn the driver when the speed limit is reached or exceeded by visual, audible or haptic (via the acceleration pedal) means. They may also registering the speed use of driver for later feedback purposes. Applications which only warn or advice the driver are called voluntary ISA and those which can directly control the speed of the vehicle and thus prevent the driver from exceeding the speed limit are called mandatory ISA. In most cases, the driver has the possibility to switch off the system.*
ITS	Intelligent Transport Systems
OEM	Original Equipment Manufacturer
	Parking Guidance System *Roadside VMS indicating directions to car parks and the numbers of available spaces in each one (or simply whether there are spaces or if it is full). Data typically comes from automated entry and exit counts of car parks. More advanced versions can include an in-vehicle display or integration of real-time parking availability into navigation aids. Guidance for on-street parking is also feasible using detection loops in each parking space to detect whether or not a vehicle is present.*
PCC	Predictive Cruise Control
TRL	Technology Readiness Level *A method of measuring product or programme concepts, technology requirements, and demonstrated technology capabilities. Based on a scale from 1 to 9, with 9 being the most mature technology.*
UTC	Urban Traffic Control *Coordination of traffic signals in a network by the use of timing plans (varying by time of day) loaded on a central computer. Green waves for road vehicles with recommended speed*
v2v	Vehicle to Vehicle communications *(See also i2v)*

Acronym	Description
VMS	Variable Message Sign *Roadside or gantry-mounted electronic sign using Light-Emitting Diode (LED) technology to display text, pictograms or both, to convey information, advice or instructions to drivers.*
VSL	Variable Speed Limits *Roadside or gantry-mounted electronic sign showing speed limit, which may be varied by road operators or police according to traffic conditions.*

1. Introduction

1.1 Background

ERTICO – ITS Europe is a public-private partnership which serves as a cooperation platform for the development and deployment of Intelligent Transport Systems (ITS) in Europe, with its principal focus on the road sector. ERTICO's vision is to bring intelligence to mobility to ensure safer, smarter and cleaner transport systems. ERTICO comprises over 100 partners, who cooperate in different research and deployment projects, platforms (cooperation activities), knowledge sharing (including ITS Congresses organised by ERTICO), as well as other advocacy and dissemination activities.

ERTICO's partnership includes several key players in the automotive industry, as well as ACEA, the European Automobile Manufacturers' Association which, together with its members, has a strong interest in making cars "greener", including actions to reduce CO_2 emissions caused by road transport. This is also a requirement to meet EU emissions targets.

ERTICO participates in the **iMobilty Forum**[2], including its **Working Group for Clean and Efficient Mobility (WG4CEM)**, which is led by Rijkswaterstaat, an agency of the Dutch Ministry of Infrastructure and the Environment. The WG4CEM produced a report in 2013 entitled "Identifying the most promising ITS solutions for clean and efficient mobility", which used expert judgement to identify the most promising ITS applications which can contribute to reducing CO_2 emissions (see further information in Chapter 2.2 and Table 1).

In November 2014, ERTICO released a **thematic paper** entitled "ITS for Energy Efficiency" which presented the current situation as well as the potential contribution of ITS measures to reducing CO_2 emissions or fuel consumption. The aim of this paper was to show that several ITS measures already exist that can contribute to this important goal.

In this context, ERTICO was approached by ACEA in order to further investigate this topic within the ERTICO Partnership with a focus on passenger cars. This study – "ITS for reducing CO_2 emission related to the usage of passenger cars", or **ITS4rCO$_2$** for short – was consequently agreed to by the ERTICO Supervisory Board. This document represents the main output of this study, which builds on the studies above (and others) using an evidence-based approach.

1.2 Scope of the study

Intelligent Transport Systems (ITS) can be defined as systems or services using Information and Communications Technology (ICT) for inland transport. It includes the collection, use and process of data from different sources necessary to optimise these systems or services.

[2] www.imobilitysupport.eu/imobility-forum

ITS applications can provide assistance, information, guidance or control to transport or infrastructure operators, administrations and/or end users (including drivers, passengers, pedestrians, logistics clients, etc). They can bring benefits such as more efficient operations (e.g. through better traffic flow and reduced congestion), improved safety and security, better services, accessibility or “comfort” for users, and environmental benefits including reducing emissions from transport.

The **present study** focuses in particular on ITS measures related to the following sectors:

- ITS measures **within passenger cars** which can reduce CO_2 emissions. These cover in-vehicle applications which use data, also from outside the vehicle, to build estimation or prediction in order to either guide the driver or control the vehicle in some way.
- ITS related **infrastructure measures** which can reduce CO_2 emissions of passenger cars, for example which influence the routing or driving dynamics of cars.

The range of ITS applications considered in this study covers those that have an **impact on the vehicle performance** in reducing fuel consumption and therefore CO_2 emissions. The study does not include applications focused on freight vehicles or public transport. Neither does it focus on ITS measures for cars which reduce actual usage, for example by promoting modal shift or suppressing trips.

The principal goals of this study are:

- As a first stage, to provide a long list of ITS solutions (overview of solutions available with a high-level assessment of fuel/CO_2 savings);
- Then, to produce a greater level of detail quantifying CO_2 emission reductions for at least two main ITS measures for each of the two sectors above (in-car and infrastructure).

The study aims to support CO_2 emission reduction through different types of measures not currently included in the current CO_2 emissions type approval test, leading to recognition of the positive contribution of ITS measures towards meeting the EU and global emissions reduction targets.

The aspect of costs is not covered in this study as full commercial deployment costs for applications under development and trials are not known. Even for more mature applications where costs are available, they will vary considerably according to the size of the deployment, the location, any legacy systems, and other local and national factors. In addition the operation and maintenance costs should be considered in the case of infrastructure measures, as well as system lifecycle. Furthermore, costs may be borne by manufacturers, car purchasers and users, road operators, public authorities, etc; whereas the benefits (CO_2 reduction and fuel savings) will not necessarily accrue to the same parties.

Most of the studies examined in this exercise include no or limited information on costs (development, deployment, operation) or lifecycle of the different applications, although some offer cost-benefit analysis but with considerable variations possible based on different scenarios even in a defined local area.

1.3 Report structure

This final report presents firstly the overview of solutions ("long list") and assessment based on input collected.

Chapter 2 presents the approach and methodology for this study, including the applications considered and the different types and formats of quantitative data available.

Chapters 3 and 4 present the findings relating respectively to in-vehicle systems and infrastructure systems (impacting vehicles). In each case there is:

- An overview table summarising the data sources and key findings;
- Descriptions of the studies or deployments which contribute (purpose, scope and key CO_2 or fuel saving related results). These are presented first for existing systems (ones that are currently deployed or available in vehicles or on public roads) and emerging systems (ones that are the subject of research or are close to market, for which results come from trials or demonstrations).

Chapter 5 provides an overall analysis of the types of systems covered in this report, followed by conclusions.

2. Methodology

2.1 Overall approach

The overall approach is to collate, analyse and (as far as possible) compare results from other projects, studies and implementations. This study does not produce new results or data.

Several previous activities have studied the CO_2 reduction potential of ITS applications, while many others have considered fuel savings, which can be taken as a proxy for CO_2 reduction. Some have involved expert judgement on potentials rather than real data, some have used modelling to predict likely effects and others have involved trials or deployments on various scales. Therefore the types of data and their reliability (or transferability) can vary widely.

The approach has been to identify and review relevant studies and deployments, focusing on those producing quantitative data. Although the scope is Europe, data from elsewhere is included where it is relevant and where solutions are potentially transferable.

As an ERTICO Partnership study, ERTICO partners have been invited to contribute data to this study, as well as ACEA partners and other stakeholders, including the iMobility Working group for Clean and Efficient Mobility (WG4CEM) and partners in relevant EU projects in which ERTICO is involved. Relevant stakeholders were contacted by email outlining the scope of the study and type of data requested. Respondents could fill in a simple results table, provide the appropriate report containing the data, or both.

2.2 Categorisation of relevant ITS applications

Several different ways of categorising ITS are possible. Given the focus of this study on CO_2 emissions (as opposed to other policy goals such as safety or user information), we have started from the classification used in the ECOSTAND[3] project, subsequently adapted by the Amitran[4] project.

The high level categorisation in Amitran[5] comprises the following six categories. The elements marked in bold text are within the scope of this study:

1. **Navigation and Travel Information** (including **navigation systems, traveller information systems**, planning support systems, inland waterway information systems);

[3] ECOSTAND (2010-2013): EU (FP7)/US/Japanese collaborative project to develop a common assessment framework for determining the impacts of ITS on energy efficiency and CO2 emissions. www.ecostand-project.eu

[4] Amitran (2011-2014): EU (FP7) project to develop a reference methodology to assess the impact of ITS on CO2 emissions in Europe for road, rail and waterway transport. www.amitran.eu

[5] http://amitran.teamnet.ro/index.php/ITS_applications

2. **Traffic Management and Control** (including **signal control, highway systems**, railway systems, enforcement systems, inland waterway systems, **parking guidance**);
3. Demand and Access Management (including electronic fee collection and other ITS supported measures demand and access measures);
4. **Driver Behaviour and Eco-driving** (including **driver assistance and cruise control**, railway systems, **driving behaviour**);
5. Logistics and Fleet Management (including public transport systems and freight transport systems);
6. Safety and Emergency Systems (including augmented awareness, eCall, inland waterway systems).

The iMobility Working Group for Clean and Efficient Mobility (WG4CEM) in its 2013 report "Identifying the most promising ITS solutions for clean and efficient mobility" identified some of the most promising applications within the scope of this study, as shown in Table 1 (next page), classified as per the ECOSTAND/Amitran categorisation above.

These estimates were based on the judgement of the 15 main authors of the WG4CEM report, using agreed assessment criteria, including implementation and deployment issues, likely user acceptance, costs and benefits, CO_2 effects, etc. Possible CO_2 reduction effects were identified using a simple three-point scale: low (0-5% reduction), medium (5-10%) and high (>10%), based on realistic outcomes at EU level, assuming that a significant market penetration is achieved. No analysis was made on the cumulative effects of different systems deployed in parallel.

The overview in Table 1 provides a good basis from which to approach the current study. Most of the applications listed in this table above are covered in this report. The ones that are not covered here are:

- *Navigation and travel information category:* Personalised multi-modal navigation tools, as the focus of this report is on car transport only.
- *Traffic management and control category:* Dynamic lane allocation, which includes reversible (contraflow) lanes and the creation of peak hour lanes e.g. by hard shoulder running on motorways. These are essentially to increase road capacity and reduce congestion, and not aimed at CO_2 reduction; in fact increasing capacity and therefore increasing traffic volumes would normally lead to increased emissions on the road treated with this measure, although some benefits could occur on alternative routes which could see a reduction in traffic.
- *Demand and access management category:* none of the applications here are considered in our study, as they focus on reducing the number of trips or the timing of them, which is not within the scope of ITS4rCO_2. Tolling and other forms of demand management do not affect the driving dynamics of vehicles (how they are driven), but rather whether, when and where they are driven.
- *Driver behaviour and eco-driving category:* Mandatory ISA is not covered as we are not aware of any such trial having been done; also car buyers are unlikely to purchase vehicles with such

mandatory controls. On the other hand, voluntary ISA (where the advice can be overridden by the driver or the system turned off if desired) is included.

Table 1: Summary of WG4CEM results: ITS applications with greatest potential for CO_2 reduction

High level category (ECOSTAND/ Amitran classification)	**ITS measure**	**Estimated possible CO_2 reduction** (percentage reduction from current levels)	**Implementation timeframe**
Navigation and travel Information	Navigation and eco-routing	5-10%	Today
	Connected eco-routing (taking into account real-time information)	5-10%	Until 2020
	Personalised multi-modal navigation tools.	5-10%	Today
Traffic management and control	Traffic signal control and signal coordination (UTC – Urban Traffic Control)	5-10% reduction until 2020, >10% reduction after 2020	Today, but much improved by 2020
	Cooperative traffic signals (i2v / GLOSA - green light optimal speed advisory and green priority)	>10%	Until 2020
	Dynamic lane allocation	0-5%	Today
	Variable Speed Limits (VSL)	0-5%	Today
	Coordinated ramp metering (motorway access control)	0-5%	Today
	Parking guidance	0-5%	Today
	Cooperative parking guidance (i2v routing)	0-5%	Until 2020
Demand and access management	Variable road pricing – Distance-based	>10%	Today
	Variable road pricing – Congestion -based	5-10%	Today
	Pay-as-you-drive insurance	5-10%	Today
Driver behaviour and eco-driving	Eco-driving support	5-10% with mobile or aftermarket solution >10% with integrated (embedded) solution	Today (mobile) Beyond 2020 (integrated)
	Mandatory ISA (Intelligent Speed Adaptation)	5-10% (0-5% potential with voluntary ISA)	Beyond 2020 (Voluntary ISA possible today)
	Cooperative Adaptive Cruise Control (C-ACC)/ Automation (autonomous platooning)	5-10%	Beyond 2020

2.3 Categorisation of result types

This study has identified different types of activity producing output. Activities include EU projects (research and development, demonstrations); national or local projects including public authorities, industry, research institutes, etc. The types of output are:

- Data on fuel savings or reduced distances driven coming from trials or deployments on public roads;
- Modelled or calculated data for CO_2 reduction, including extrapolated or scaled-up data (results of impact assessment studies);
- Estimations of potential CO_2 reduction, for example from state-of-the-art overview reports or expert groups.

These present different levels of data confidence or robustness, as well as scalability and transferability. This report concentrates on quantitative and validated data which can be referenced, rather than estimations or expert opinion as is presented in Table 1.

The reliability of data depends on the scope of the trial or implementation, for example the extent to which data from a local trial site can be applicable globally depends on local or national specificities of the trial site. Factors to be considered include:

- Range of different geographical area(s), i.e. a single trial site or several in different countries;
- Type(s) of road network(s) involved (urban, rural, motorway, etc.) and speed limits;
- Traffic situation (fluidity) and vehicle mix;
- Environmental conditions;
- Year of study (recent or old);
- Trial or evaluation period;
- Number of vehicles or drivers involved;
- Vehicle types: driveline characteristics (manual, automatic, hybrid), fuel type, weight, load;
- Distances driven;
- Approach to evaluation where two or more ITS applications are implemented together;
- Means of comparing to a base situation without the ITS application.

Our approach in the next stage of the study will be to include these factors (where known) along with the data coming from studies, trials or deployments, in order to put their results in context.

2.4 Data collection and measurement units

Data has been collected from a number of stakeholders including ERTICO partners, ACEA partners, participants in relevant projects, iMobility Working Group members, conference papers, Internet search, etc. Data is summarised in the introductory sections of Chapters 3 and 4.

Measurement units used are most commonly a percentage reduction in fuel use from a situation without the ITS measure to one with the measure being used. In some cases, fuel use (before and after) in litres per 100km (or miles per gallon, which have been converted to litres/100km) are given and in others a reduction in absolute CO_2 emissions in tonnes was given (per distance or time frame). Fuel use savings are assumed to be equivalent to CO_2 savings for the purposes of this report. While this would be true in percentage terms, the absolute reduction in CO_2 emissions from a given fuel saving would vary according to the fuel being used: CO_2 emissions from a litre of petrol are 2.39kg and from a litre of diesel 2.64kg[6].

In addition to statistical data, other sources are able to make a more limited contribution to this study. These include:

- Projects or activities that have developed or implemented CO_2 assessment methodologies or tools for ITS applications. These comprise the EU projects ECOSTAND, Amitran and ICT-EMISSIONS. Their outputs are valuable in terms of defining approaches to validation and impact assessment for future studies or trials. Other activities have developed tools for analysis of energy savings or providing eco-routing advice.
- Papers from working groups providing overviews, expert consensus or recommendations. Specifically, these are the ERTICO Thematic Paper on “ITS for Energy Efficiency” (November 2014) and the iMobility Working Group for Clean and Efficient Mobility (WG4CEM) which produced the report “Identifying the most promising ITS solutions for clean and efficient mobility” in November 2013.

2.5 Assessment methodology used in the contributing studies / activities

The different studies have adopted different methodologies and thus the confidence in the results varies. We therefore put the main emphasis on results which have been validated in a robust way, e.g. using the FESTA methodology. The two key relevant projects in this regard, which also covered a range of ITS applications, are eCoMove and ICT-EMISSIONS.

2.5.1 Validation

Validation aims to ensure that a system both functions and meets its objectives. This involves defining the user needs, use cases of the system(s) and functional requirements. Then the aspects to measure are defined, including how they will be measured and the criteria for acceptance. The V-Model work flow diagram shown in Figure 1 is a typical example of a validation process used in software and system engineering practice, taken from the eCoMove project.

[6] Source: www.ecoscore.be/en/how-calculate-co2-emission-level-fuel-consumption

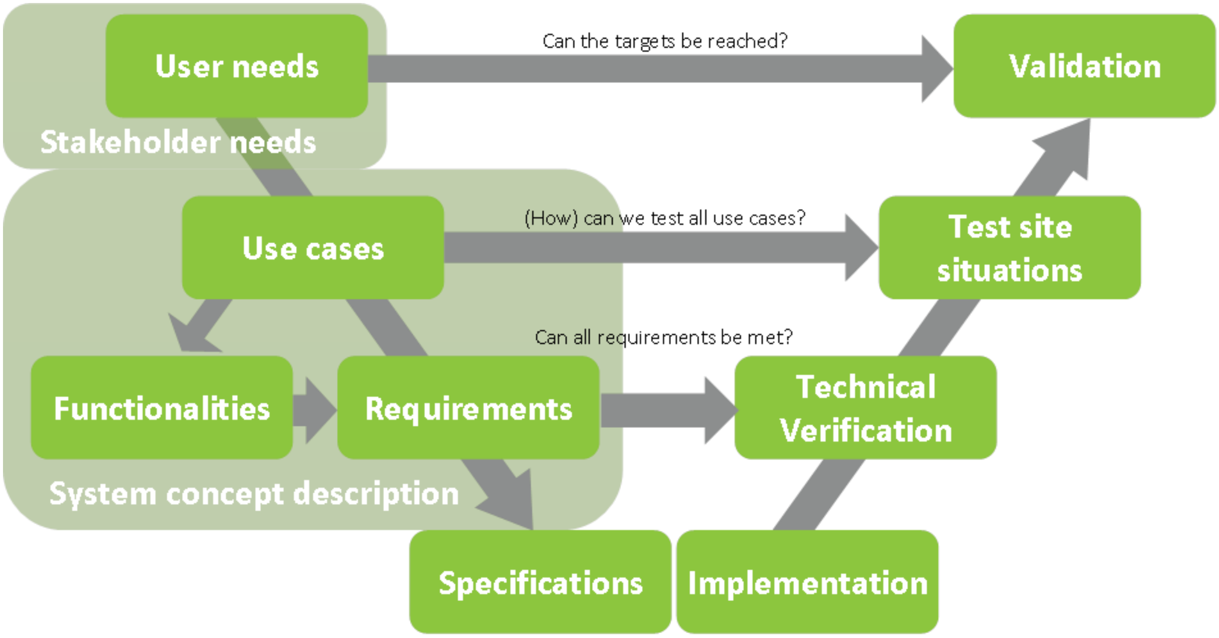

Figure 1: V-Model approach for validation (example from eCoMove project)

The validation methodology is crucial in order to be able to compare different solutions, in particular for ITS solutions claiming reduction of CO_2 emissions. It is necessary to know in which conditions the validation testing was performed because results strongly depend on:

- topography: flat or hilly region;
- type of network: city, suburban, major road, rural road, motorway;
- users, type of drivers (driver behaviour and knowledge/familiarity of their route and surrounding network).

For the assessment of Cooperative systems, simulation of the traffic network is important and should be part of the validation methodology in combination with:

- field tests mainly to calibrate simulation parameters but also to validate the proposed ITS solution using a limited number of vehicles;
- driving simulator testing, in order to perform reproducible tests with many drivers.

The traffic network simulation integrating both field tests and driving simulator tests provides the capability to validate the Cooperative ITS solution on the local network.

As a consequence of the strong dependency mentioned above, scaling-up of results is not possible unless we have the same conditions (topography, type of network, etc). This is a major difference in comparison to ITS solutions which aim to improve safety, for example.
In this study we looked closely at the validation methods used by projects, in order to accept the CO_2 reduction figures claimed.

2.5.2 Impact assessment

Impact assessment evaluates the potential impact of the system in real-life situations. This can include future-casting to different years and scaling up to different geographical, population or network levels. Impact assessments can also take into account different future scenarios (fleet types, policies, prices, attitudes, levels of technological innovation, etc).

Modelling is required to achieve this and the Amitran project provides guidance on the approach to take in modelling the potential impact of an ICT solution on CO_2 emissions (see www.amitran.eu).

A key project contributing to this study that has carried out an extensive impact assessment is ICT EMISSIONS, scaling up data to city level and to years 2014 and 2030, based on different penetration rates for the systems assessed. Some notable features of impact assessment are:

- Relative levels of CO_2 emission reductions (and other effects) at different penetration rates. In general the relationship will not be linear (e.g. a 60% penetration rate will not deliver double the benefit of a 30% one), but will depend on aspects like road capacity, effects on non-equipped vehicles and so on;
- Consideration of what other changes are likely, independent of whether the system is deployed or not. Parallel changes to infrastructure, prices, regulations, improvement and penetration of other technologies or applications, may either increase or reduce the beneficial effects of the ITS measure being considered.

3. In-vehicle systems

3.1 Overview

The following table gives an overview of in-vehicle systems: stand-alone applications or ones which use real-time external data, such as mapping, traffic conditions. etc. These focus mainly on eco-routing and navigation, eco-driving, cruise control, Intelligent Speed Adaption (ISA), etc.

Table 2: Data collection summary table for stand-alone in-vehicle systems

Project or activity name	ITS measure	Description	Type of work (trial, study, etc) and year	Achieved reduction
1. COSMO	Eco-driving and Driver Behaviour Change	The service suggests in real time how to drive in order to determine the lowest fuel consumption	On-road trial in Italy in 2013 with 33 drives each without and with the system	Reducing the fuel consumption and CO_2 emissions in 9 % on average. This reduction is even higher in the areas close to I2V equipped traffic lights, being able to achieve reductions of up to 15 %
2. eCoMove	Eco-driving support	In-vehicle eco-driving support (visual HMI with advice on gear selection, speed, etc)	On-road trials in 2013 (1 Ford car, 2 Fiat cars, 1 BMW car)	Average of 9.7% fuel savings with the system (results ranging from minimum 3.2% to maximum 18.6%)
3. eCoMove	Eco-driving support	In-vehicle eco-driving support (visual HMI with advice on gear selection, speed, etc) combined with haptic pedal	Driving simulator studies in 2013	Average of 15.9% fuel savings on urban roads (50km/h speed limit) and 18.4% on interurban (70km/h speed limit)
4. ICT-EMISSIONS	Navigation and eco-routing	Real-time in-vehicle navigation for eco-routing, by PDA or mobile phone	On-road trials in Madrid, 2013 + modelling	Modelled results for 2014 car fleet: under medium traffic conditions 1.1% CO_2-reduction with 10% penetration rate, rising to 4.7% with 90% penetration rate. In congested traffic, benefits are higher: 2.2% with 10% penetration, up to 8.2% reduction with 90% penetration. Under free flow conditions, benefits are higher still: 5.9% to 9.5% depending on penetration rate.

Project or activity name	ITS measure	Description	Type of work (trial, study, etc) and year	Achieved reduction
5. GERICO (Continental)	Eco-driving	Haptic pedal to give advice on gear shifting	On-road trials with 24 participants, 1 vehicle	Reduced CO_2 of 15.8gkm (7.7% reduction) with visual and haptic HMI for gear shift advice (compared to negligible saving using visual HMI only)
6. High Efficiency CO_2 (HECO2)	Connected Eco-Driving ("intelligent eco-coaching")	Multi-modal HMI (visual/sound/haptic) for driver coaching and teaching on driving best practices, in connection with predicted data from e-Horizon	On-road trial, 2014-2015	Potential gains: up to -10% vs statistical standard driving styles.
7. High Efficiency CO_2 (HECO2)	Connected Energy Management	Predictive Control and Adaptation of Driving Strategies, as Intelligent deceleration assist, intelligent traffic light assist, using radar and connection to infrastructure, dynamic eHorizon	On-road trial, 2014-2015	From 2% to 5%, according to powertrain architecture
8. ISA – UK	Intelligent Speed Adaptation	Project in UK which equipped 20 vehicles with a voluntary ISA system and the vehicles were then used by 79 drivers (private and fleet) for their everyday driving over a period of 6 months each (4 months with ISA enabled).	4 separate long-term on-road trials in Leeds and Leicester areas, UK, 2006	The calculated fuel savings in the trials with the 79 participants were 0.4% on 30 mph (48km/h) roads, 1.2% on 40 mph (68km/h) roads and 3.4% on 70 mph (112km/h) roads. Full compliance would increase the savings on 70 mph roads to 5.8%.
9. FLEAT	Eco-driving	New vehicles with fuel economy devices + training and incentives (note this is essentially a non-ITS measure)	On-road trial with 809 vehicles	6.4% reduction in CO_2 for light vehicles (cars and vans) with eco-driving
10. NAVTEQ navigation	Navigation	Trials comparing navigation systems with no system, to determine effects on behaviour	On-road trials in 2 German cities, 2100 trips made	12% reduction in fuel use

Project or activity name	ITS measure	Description	Type of work (trial, study, etc) and year	Achieved reduction
11. NAVTEQ eco-routing	Eco-routing	Trials comparing fastest with greenest route	On-road trials in several cities (Europe + USA)	Fuel savings of at least 5% between fastest and greenest route, with minimal increases in travel time (a few minutes)
12. ICT-EMISSIONS	Adaptive Cruise Control (ACC)	Automatic velocity control subject to the distance to the preceding vehicle	Simulation of several thousand ACC vehicles for urban ring road and city streets, 2013	Maximum modelled impact: 7.5% CO_2 reduction (for urban ring road with 100% ACC penetration rate); 4.5% with 60% penetration and 1.5% reduction with 20% penetration. On city streets, savings were much lower (between 0.25% and 2.25% depending on penetration rate)
13. ecoDriver	Eco-driving	Large scale EU project which developed and tested eco-driving applications using different HMI (embedded, aftermarket and Smartphone)	On-road trials at 9 sites in 7 EU countries (different variations of the system trialled).	Data will be available in January 2016. However at least 10% saving in fuel/CO_2 envisaged, aim is for 20%.
14. euroFOT	Navigation	Large scale EU Field Operational Test: trial of both mobile and built-in navigation devices	On-road trials at 3 sites with 99 car drivers	3% saving in fuel/CO_2 for built-in device. No significant change for mobile device.
15. euroFOT	Adaptive Cruise Control (ACC) with Forward Collision Warning (FCW)	Large scale EU Field Operational Test	On-road trials at 3 sites with 178 car drivers	2.1% reduction on motorways for car-following situations. No significant change on other roads. Scaled up effect on motorways assessed as 0.96% fuel reduction.

3.2 Navigation systems / Eco-routing

Navigation systems for cars are based on maps to guide the driver through the network. If the system integrates up-to-date traffic information (e.g. RDS-TMC information) it is dynamic navigation. Some systems are enhanced by specific information such as estimated fuel consumption, including real-time information. This is eco-routing or eco-navigation.

They influence the pre- and on-trip route choice made by the driver and hence influence the total distance driven. A paper by TNO[7] reported that drivers with dynamic navigation systems drove 16% fewer kilometres than those without. Vehicles with a navigation system opt more frequently for less congested routes.

A 2008 data collection project by **NAVTEQ and NuStats**[8] looked at **how navigation systems changed driver behaviour**. It focused on three groups of drivers in the Düsseldorf and Munich metropolitan areas. The groups were (1) Drivers without a navigation system, (2) Drivers provided with a navigation device; and (3) Drivers provided with a navigation device enabled with real-time traffic. All the participants' cars were fitted with logging devices to track the routes they drove as well as their driving speeds. In total, the study reflected more than 2100 individual trips and over 20,000 kilometres of driving.

The results showed that the drivers with navigation systems (both with and without real-time traffic) realised fuel efficiency increases of **12%** while their fuel consumption fell from 8.3 to 7.3 litres/100 km. This increase in fuel economy translates into a 0.91 tonne decrease in CO_2 emissions every year per driver – an annual 24% decrease in emissions compared to those of the average non-navigation user.

Another finding from the study revealed that the participants with navigation systems drove less distance per trip, on average. The data suggests that each of those drivers with a navigation system would travel approximately 2500 fewer kilometres annually.

Eco-routing was the subject of another NAVTEQ study[8] which, in partnership with Magneti Marelli, tested the potential fuel savings of this concept by examining calculations comparing the fastest Route to the greenest Route under several driving scenarios taken from cities including Paris, Frankfurt, New York, and Chicago (both city and suburban). All scenarios realised per-trip fuel savings of at least 5%, and often more, while extending the trip's time by mere minutes, if at all.

The EU project **euroFOT** (European Large-Scale Field Operational Tests on In-Vehicle Systems) tested navigation systems (not specifically eco-navigation). Both mobile and embedded devices incorporating real-time traffic information were tested in BMW and Daimler cars, with 99 drivers. The drivers drove

[7] Vonk, T., Rooijen, T., van Hogema, J., Feenstra, P. (2007). Do navigation systems improve traffic safety? Report TNO 2007-D-R0048/B. Paper presented at TNO Mobility and Logistics. Soesterberg.
[8] NAVTEQ (2010), NAVTEQ Green Streets™ White Paper

the same car with no device, with the mobile device and the built-in device in different orders, for about a month each. Drivers were to press a specific button if they were making a trip where they were already familiar with the route, as in such cases navigation systems provide less benefit.

Both the mobile and built-in device reduced travel time, by 7% and 9.4% respectively, however only the built-in device reduced average trip length (by 6.8%). Fuel consumption was reduced by **3%** compared to the baseline when using the built-in device. No significant reduction in fuel use was achieved with the mobile device.

In the **ICT-EMISSIONS** project, green navigation was tested in Madrid using mobile devices in cars. Results were scaled up to city level for two years: 2014 and 2030, to different penetration rates (from 10% to 90% of vehicles equipped) and different traffic conditions (free-flow, medium and congested). Reductions in emissions on a macro (city-wide) level ranged from 1.1% to 9.5%, with greater absolute benefits as penetration rates rise and greater benefits in free-flow conditions. However, as penetration rates rise, the net benefits increase more slowly, as with more vehicles equipped and drivers following alternative eco-routes, these routes become more saturated and less beneficial.

A key finding is that the benefits of green navigation fall as the network becomes more congested because in a congested network there is a limit to the routing optimisation that can be achieved. The graphs below summarise these results.

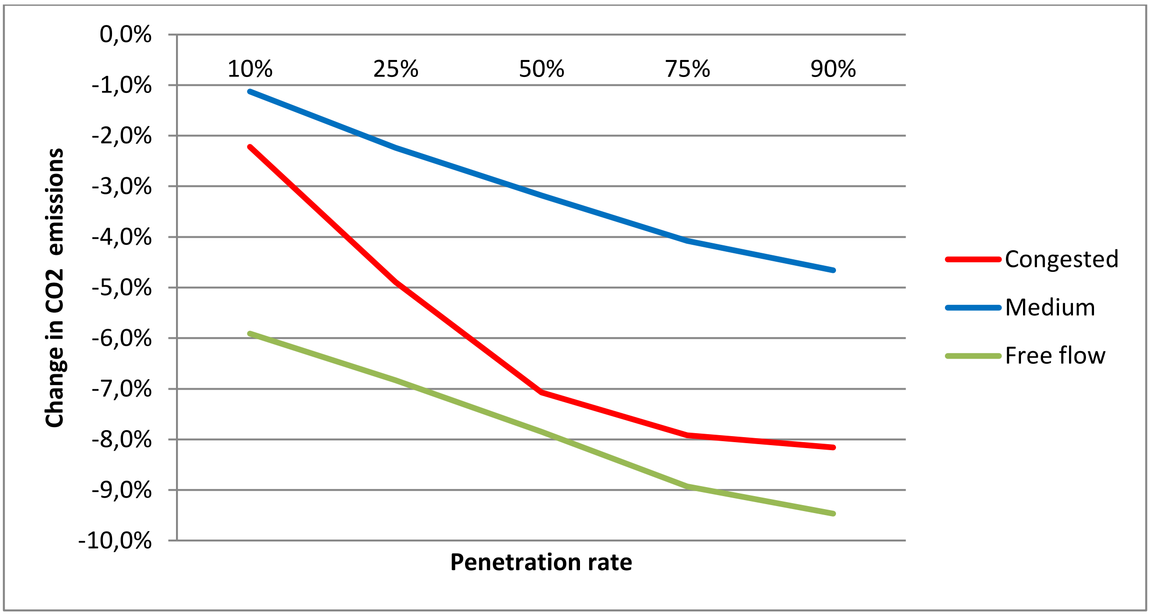

Figure 2: Modelled effects of eco-navigation advice on CO2: 2014 (ICT-EMISSIONS project, Madrid)

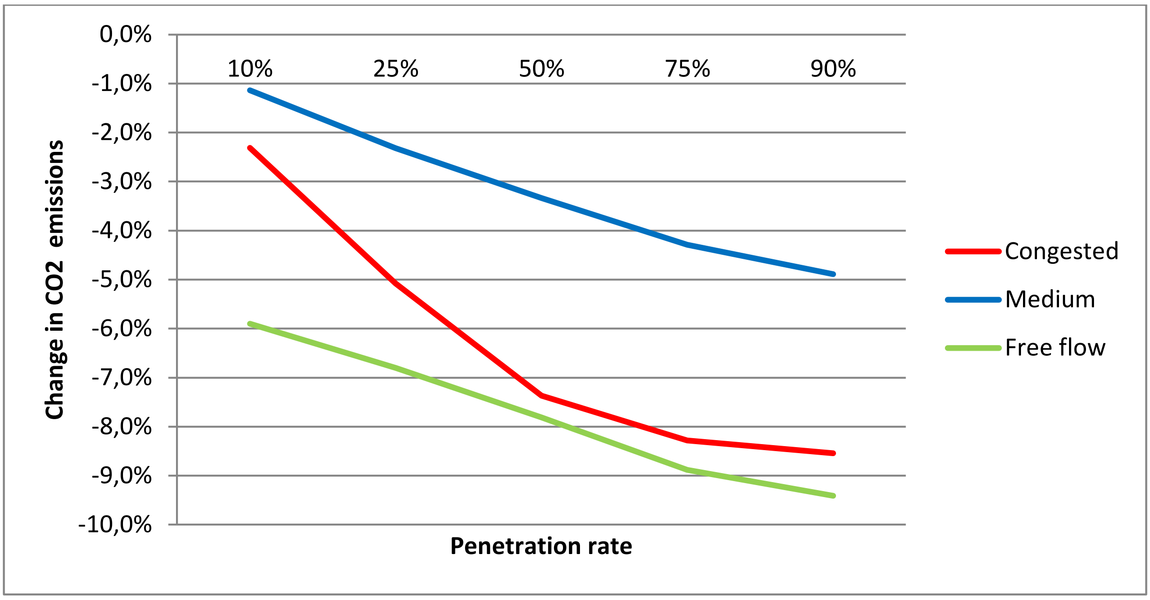

Figure 3: Modelled effects of eco-navigation advice on CO2: 2030 (ICT-EMISSIONS project, Madrid)

3.3 Driver behaviour changing/advice, including speed advisory and eco-driving systems

Eco-driving systems recognise driving behaviour and provide support to the driver in terms of on-trip advice and post-trip feedback/feed-forward.

These systems are designed to influence the driver's behaviour regarding speed, headway and driving dynamics (use of gears, engine braking, anticipation, etc). For example, an extended headway reduces the need for braking and acceleration. This would reduce the average fuel consumption. The overall fuel savings depend on the driver's behaviour and on the situation (e.g. urban, motorway or mixed, congested or not, hills, bends or other obstacles).

Eco-driving aids may be integrated into the vehicle (OEM systems), provided as an after-market option tailored to the vehicle, or take the form of fully nomadic systems based on Smartphone applications, with communications between the telephone and the vehicle's CAN-Bus.

3.3.1 Current eco-driving systems

A report for the **RAC Foundation** in the UK[9] noted outcomes from 25 different (non-comparable) studies worldwide between 1985 and 2011 which involved eco-driving. Fuel savings ranged widely, from a 3% worsening to a 35% improvement, although most results were in the range of an improvement of between **5%** and **20%**. However this did not only focus on ITS measures for eco-driving but also measures such as driver education and training, incentive schemes, advice on non-

[9] Wengraf, I (2012), for the RAC Foundation, "Easy on the Gas: The effectiveness of eco-driving", Table 3.1: "Reported fuel savings from eco-driving studies"

driving aspects of car use (loads carried, use of air conditioning), etc. While these non-ITS measures certainly have potential to reduce CO_2 emissions (and have been shown to do so), they are not considered further within the scope of this report.

NAVTEQ and Magnetti Marelli[8] collaborated to look at the potential fuel savings enabled by map-based eco-driving. Drivers who chose to follow eco-driving recommendations realized fuel savings of **5% to 15%**.

In **eCoMove**, eco-driving applications were trialled by Ford, Fiat and BMW. The eco-driving HMI (providing eco-information: visual and haptic pedal for gear shift) in a Ford Focus estate resulted in an average fuel reduction of **11%** over 40 trips in the Aachen area, with a standard deviation of 7%. With Fiat, two cars (a Fiat 500 and a Fiat Qubo) were driven around a mixed urban-interurban route in the Turin area, with an ecoSmartDriving visual HMI. An average fuel reduction of **4.5%** was achieved among the 27 participating drivers. At BMW, the ecoAssist application (including coasting mode, using a Head-up Display and dashboard display, with eco-messages, map, navigation and driving support) installed in a BMW 535i demo vehicle resulted in fuel savings of **18.6%** with a standard deviation of 1.1%, over 10 runs on a 95km mixed urban-interurban route near Munich.

In **ICT-EMISSIONS**, eco-driving in Madrid was tested and also a simulation was undertaken for Turin. While the trial results in Madrid gave CO_2 reduction benefits of between 4.5% and 16.2% (average benefit of 5.5% on motorways and 12.5% on urban roads), the impact assessment showed much smaller benefits, or (rarely) even disbenefits (worsening) when modelled with higher penetration rates. This is because with 75% of drivers eco-driving on a congested urban network, the network becomes saturated (due to longer vehicle headways) and the resultant congestion then increases emissions. Modelling for eco-driving was thus found to be a very delicate procedure as small differences in road capacity can cause negative effects on already congested networks.

Finally, non-ITS eco-driving solutions are also available. Although these are not the focus of this report, for illustrative purposes, the EU project **FLEAT** trialled eco-driving training for car, truck and bus drivers, using professional trainers, combined with new vehicles with fuel economy devices as well as incentives. A trial comprised 809 light vehicles, 332 trucks and 332 buses. For light vehicles, the fuel reduction was 6.4% (for trucks and buses it was slightly more) and the cost of the training could be recouped in savings in between 1.6 and 5.2 years.

3.3.2 Emerging eco-driving systems

The **GERICO project** by Continental[10] demonstrated an intelligent Human-Machine Interface (HMI) assistant to induce drivers in CO_2 reduction efforts. It calculates and recommends the optimal speed, gear ratio, and pedal action for each road type. A gauge indicator predicts fuel consumption in actual conditions and can recommend manual stop and go. It also optimises a trip planning profile from a

[10] Huber, T (2015), presentation entitled "Driver Influence & advance Driving Strategy improves CO_2 Saving in Real Driving"

navigation system, communicates with external traffic control and provides an analysis of the driver's efficiency. Overall fuel and therefore CO_2 reduction from all of these measures was calculated to be 20% on average.

In particular the GERICO project carried out a trial on its AFFP **haptic pedal for advising gear change**, using 24 drivers and a BMW 530i car (manual transmission, 6 gears) on a 50km urban route around Munich. The route was driven without any gear change information, with visual information only, and with visual (screen) and haptic (pedal) information together. Without any information, fuel consumption was 8.81 litres/100km, with CO_2 emissions at 204.4 g/km. With visual information only, improvements were only negligible (8.79 litres/100km and 203.9 g/km respectively). However with the addition of a haptic pedal HMI in addition to visual advice, a **7.7%** improvement on the base situation was noted, with fuel consumption was 8.13 litres/100km, with CO_2 emissions at 188.6 g/km. Use of the 6^{th} gear in urban traffic was significantly increased using this HMI and use of the 4^{th} gear significantly reduced.

In the **eCoMove** project, the eco-driving HMI with the haptic pedal was also used in a trial with a driving simulator. 30 people undertook simulated drives with and without an eco-driving advice system using a visual HMI (see Figure 2 below) and a haptic pedal at DLR in Braunschweig, Germany and the outcome was an average **15.9%** calculated reduction in fuel use (and hence emissions) on a simulated urban road (50 km/h speed limit) and **18.4%** on a simulated rural road (70 km/h limit). Results varied widely from a minimum of 1.3% saving to a maximum 36.8% saving, and a standard deviation of 11%.

Figure 4: Visual HMI for DLR eco-driving simulator (eCoMove project)

This trial at DLR involved traffic lights in urban zones (50 km/h speed limit) and non-urban zones 70 km/h limit). Curves and stop signs also featured, in both urban and non-urban zones. The simulator was used with a simulated lead car (i.e. the “driver” was behind another car) and without a lead car (i.e. clear road ahead). Different advice speeds were given on approaching these features (traffic light, stop sign, curve). The greatest reductions were achieved on the approach to urban and rural traffic lights without a lead car, where a low recommended speed for traffic light approach was given (26.3% savings in urban situation, 34% in rural situation). Situations with a lead car gave slightly lower levels of benefits (23.8% and 22.4% savings respectively). Emission reduction benefits were much lower (between 1 and 2%) where no reduced speed was advised before the traffic light (i.e. normal road speed limit).

A simulator study was carried out in China in 2013 by **Tonji Univerity, Shanghai**. The tested applications were two in-vehicle HMI systems giving advice to the driver: one of them a Green Wave speed guidance strategy and the other an Eco-driving speed guidance strategy. This comprised building a new multi-vehicle driving simulator platform taking into account driver interactions. The two strategies were then programmed through the script language provided by Virtools software.

The section of road modelled was a 1.7km stretch of urban highway in the suburbs of Shanghai (2x4 lanes with 80km/h speed limit), which included two signalised intersections. The trials were carried out in a simulator using 15 volunteer “drivers”, each one making four runs in each of three scenarios: no system, Green wave system and Eco-driving system.

Results from the Green Wave speed advisory strategy were an average fuel reduction saving of 13% (45.7ml of fuel used on average to drive the section of road, compared to 53ml with no system used). With the Eco-driving strategy benefits increased to a 25% CO_2 saving (39.9ml of fuel used). Both systems reduced the number of stops made by the driver in almost equal measure, but overall time savings were negligible (reduction from 75 seconds with no system to 70 seconds with the Green Wave strategy and 72 seconds with the Eco-driving strategy). Benefits however were lower in the case of a lead vehicle (in heavier traffic, drivers’ speed would be constrained by having to keep a safe distance from the vehicle in front, hence speed advice would no longer be beneficial).

3.4 Adaptive Cruise Control

Adaptive Cruise Control (ACC) provides automatic velocity control which is subject to the distance to the preceding vehicle. It influences acceleration behaviour and this provides potential for emission reduction.

The **euroFOT** project tested ACC (together with Forward Collision Warning – FCW) on cars and trucks. For the car tests, data from 178 drivers is available, using Volvo, Ford and Volkswagen cars. The treatment period varied by site but was at least 6 months for the baseline and 6 to 9 months for the treatment period using the application. The tests included all road types.

The benefit of ACC was only significant on motorways and in a situation where the trial vehicle is following another vehicle. In this situation there as a reduction in average speed of 0.3% and a reduction in fuel consumption of **2.1%**. For urban roads there was a reduction in average speed of 0.2% but no significant fuel savings.

ICT-EMISSIONS simulated ACC by closely coupling a microscopic traffic simulator and driver simulator and by online computing of the driving behaviour of ACC vehicles. Tests were done for an urban ring road (highway) in Munich and city districts in Munich and Turin. These were modelled for ACC penetration rates of 0% of vehicles (baseline), 20%, 40%, 60%, 80% and 100%.

In general, higher penetration rates gave better results in terms of emission reductions, except for between 80 and 100% penetration on urban streets, where there was a slight fall in the benefits. On the highway ring road, modelled benefits at the macro level were **1.5%** reduction in CO_2 emissions for a 20% penetration rate, **4.5%** reduction at 60% penetration, and **7.5%** reduction with all vehicles equipped (100% penetration). For urban roads, the respective figures for 20%, 60% and 100% penetration were 1%, 1.2% and 1.5% for Munich, and 0.25%, 1.5% and 2.25% for Turin. Thus ACC offers benefits principally on faster roads and in free-flow conditions, whereas benefits in urban areas are small.

4. Infrastructure systems impacting vehicles

4.1 Overview

The following table gives an overview of infrastructure systems impacting vehicles, focusing on traffic signals and intelligent parking. For traffic signals, there is some overlap with the preceding chapter on in-vehicle systems, as some emerging or currently research systems using v2i communications are effectively in-vehicle systems but using real-time data from the infrastructure. Applications which regulate and control the traffic signals, as well as any off-vehicle information (e.g. VMS – Variable Message Signs) are described here, while in-vehicle driver information HMI systems are covered in the previous chapter.

Table 3: Data collection summary table for infrastructure systems

Project or activity name	ITS measure	Description	Type of work (trial, study, etc) and year	Achieved reduction
1. ADAC/TUM study on reduction of emissions using green waves	Urban Traffic Control (UTC) - Traffic signal control and signal coordination	Adaptive urban traffic management with traffic signal controllers coordinated and updated every 5 minutes	On-road before and after study in Ingolstadt (DE) in 2008 using FCD then modelled onto 7 cars (in 2013).	11 to 17% reduction in CO2 emissions (average 15%) for treated vehicles
2. eCoMove	Urban Traffic Control (UTC)	Dynamic green wave for traffic lights	Microscopic traffic simulation model of a corridor in Helmond (NL), 2013	4.1% CO_2 reduction in peak periods and 3.6% in off-peak periods (all traffic, not just vehicles benefitting from a green wave).
3. ICT-EMISSIONS	Urban Traffic Control (UTC)	Synchronised traffic signals on 5 intersections	Modelling based in Turin: 4 vehicles / 2 days UTC off, 4 days UTC on	CO_2 savings of 8% in normal traffic conditions and 4.5% in congested conditions
4. Tonji University, Shanghai	Green wave and eco-driving speed	Driving simulator studies of in-car HMI giving driver advice on speed for (a)	Simulator study with 15	(a) 13% fuel reduction (hence estimated CO_2 reduction the same) for

Project or activity name	ITS measure	Description	Type of work (trial, study, etc) and year	Achieved reduction
	guidance	riding a green wave of traffic signals only and (b) green wave speed + eco-driving advice.	volunteers on urban highway, Shanghai, 2013	Green wave speed guidance strategy (GWSGS). (b) 25% reduction for Eco-driving speed guidance strategy (EDSGS)
5. Compass4D	Energy Efficient Intersection Service (EEIS) including GLOSA	Priority for selected vehicles at traffic signals and on-board information to drivers to anticipate current and upcoming traffic light phases and adapt their speed accordingly (GLOSA)	Trial in 7 European cities, 2014-2015	Data expected in October 2015
6. ICT-EMISSIONS	Variable Speed Limits (VSL)	Recommended variable speed 80, 70, 60, 50 or 40 km/h on an urban motorway with normal speed limit of 90km/h	Trial in Madrid, 2013, using floating car data	CO_2 savings of 1.8% on average both in normal and congested flow
7. LA Express Park	Intelligent Parking Management / Dynamic pricing	Data collection and analysis. Dynamic pricing of on-street parking to achieve increased efficiency, customer service and reduce congestion caused by circling traffic seeking spaces	Trial in Los Angeles, 2012-2013	Circling traffic reduced by 10% in Los Angeles project area
8. COSMO	Dynamic Parking Management	Service giving indications on parking space status, showing them on on-board units (OBUs), a smartphone application and a variable message sign (VMS)	Trial at two car parks in Salerno, Italy, 2013	Due to the reduction in average time to park, the average reduction of CO_2 emissions is 7%.

4.2 Traffic management and control systems

Traffic management and control includes traffic signal control and optimisation, lane allocation and control, dynamic speed limits, access management and parking management.

An investigation by **ADAC** (German Automobile Club) in cooperation with the Traffic Engineering Department of the **Technical University of Munich (TUM)**[11] showed that **adaptive traffic control with green waves** can reduce fuel consumption (and therefore the carbon dioxide emissions) by **15%**. It can also reduce nitrogen oxide emissions by 33%, the particulate emissions by 27%.

The trial involved a before and after study of the “BALANCE” adaptive traffic control system in Ingolstadt, Bavaria (two days in June 2006 as baseline and two days and June 2008 with the system), as part of the TRAVOLUTION project. The BALANCE system involves the network controller determining the best traffic lights for the entire transport network (46 intersections treated) and all road users, and is adapted to the current traffic situation.

In the “before” trial, FCD (floating car data) was retained for three routes and a total of 425 trips were made. Typical traffic characteristics were drawn from local detector data, e.g. Induction loops and travel times from ANPR cameras. Criteria for the selection of typical traffic behaviour were traffic volume, average speed, number of stops and elimination of cars with an acceleration or deceleration rate of over 4 m/s^2. Comparable and representative for the traffic situation journeys were based on the 25% or 75% quartiles.

Driving profiles were determined by TUM for seven different test vehicles comprising small and mid-range cars (3 petrol and 4 diesels) built between 2004 and 2012. The before and after driving cycles were traced onto ADAC’s exhaust dynamometer and mapped to these seven vehicle types to determine fuel consumption and emissions.

The results showed that the BALANCE adaptive network control optimises traffic signals not only on individual routes, but also improves the flow of traffic across the main road network of Ingolstadt. The exhaust gas measurements of representative driving profiles show the pollutant reduction potential as **15%** on average for fuel economy and CO_2 (ranging from 11% to 17%). The results for each of the seven vehicle types are shown in the following table. Reductions of other emissions included 33% for nitrogen oxides (NOx), 27% for nitrogen dioxide (NO_2), 27% for particulate emissions and 13% for hydrocarbons.

[11] ADAC eV (2013). ADAC-Test Emissionsminderung durch Netzsteuerung

Table 4: ADAC / Technical University of Munich adaptive green wave study results for CO_2

Car size and year built	Fuel type and emissions standard	CO2 g/km before / after adaptive traffic control[12]	CO2 reduction (g/km and percentage)
Mid-range, 2004	Petrol Euro-4	166g / 143g	23g / 14%
Lower mid-range, 2012	Petrol Euro-5, direct injection	122g / 106g	16g / 13%
Mid-range, 2011	Petrol Euro-5, direct injection	142g / 119g	23g / 16%
Mid-range, 2005	Diesel Euro-4 without particulate filter	144g / 124g	20g / 14%
Mid-range, 2008	Diesel Euro-4 with particulate filter (closed system)	129g / 108g	21g / 16%
Small, 2012	Diesel Euro-5	81g / 72g	9g / 11%
Mid-range, 2012	Diesel Euro-6, exhaust gas recirculation and low compaction	113g / 94g	19g / 17%

In **eCoMove**, a simulation study was done using the microscopic traffic simulation model VISSIM. The test network concerned an urban corridor in the Dutch city of Helmond, covering 4 signalised intersections. The baseline scenario was the existing situation of the test site with actuated controller. Traffic volume consists of 95% cars and 5% trucks. Simulation time was 2 hours for both peak (evening) and off-peak period. For this Greenwave application, the intersection timing was adjusted in such a way that a vehicle platoon gets green throughout the main directions thus avoiding having to stop at the signal. 10 test runs were executed in each of the peak and off-peak scenario.

Modelled CO_2 emission reductions for cars in the peak period were from 227.3g/km (baseline) to 217.9g/km (with the system) for the peak period, equating to a 4.1% saving. For the off-peak period, the reduction for cars was from 211.3g/km to 203.7g/km, i.e. a 3.6% saving.

The **ICT-EMISSIONS** project modelled the effect of Urban Traffic Control on five intersections in Turin. The UTC was turned off for two days to provide a base case (17 trips made), and then measurements were taken during four days with the system on (43 trips made). Four Fiat cars were used for the trial. As well as significant savings in travel time (between 21% and 26.5%), CO_2 emission savings of 8% were achieved in normal traffic conditions and 4.5% in congested conditions. A micro simulation carried out on UTC on a corridor in Rome gave similar results: 4.8% CO_2 emission reduction.

ICT-EMISSIONS also tested Variable Speed Limits (VSL) on a 7km length of 90km/h 3+3 lane urban motorway in Madrid. Speeds can be reduced to 80, 70, 60, 50 or 40 km/h depending on the

[12] Before and after figures are approximate (±2g/km) as they are extrapolated from a graph.

circumstances. Over 2000 runs were made using three Fiat cars. Traffic data (intensity, average speed and occupancy) was also collected from traffic loops every five minutes.

Results were savings in fuel of 1.1%, 1.9% and 2.6% for the three cars used, weighted average of 1.8%. These were valid for both normal and congested flow conditions (savings under congested conditions were marginally higher, by 0.1%).

The **Compass4D** project includes the demonstration of an Energy Efficient Intersection Service (EEIS) which aims to reduce energy use and vehicle emissions at signalised junctions. The major advantage of a cooperative EEIS using i2v (infrastructure-to-vehicle) communication is the availability of signal phase and timing information in the vehicle. Presenting this information to drivers enables them to anticipate the current and upcoming traffic light state. The use cases relevant to CO_2 reduction are:

- Green Light Optimal Speed Advisory (GLOSA): drivers receive traffic light state information and advice for the most energy efficient speed and deceleration strategy to approach the intersection. On arterials with multiple intersections this implies platoon progression.
- Idling stop support: time-to-green information is used by the in-vehicle application for engine control and engine turn off.
- Start delay prevention support: time-to-green information is used by the in-vehicle application to minimise time loss at the start of green due to engine start, reaction time, etc.

Trials of these systems in seven cities have only recently finished so data is not yet available. It will however be included in updates to this report.

4.3 Parking guidance

By introducing a **Dynamic Parking Guidance System** that indicates available parking spaces, it is possible to anticipate present and expected traffic intensity, thus enabling a better spread of motorists across the city. Parking guidance using VMS are already widespread in Europe

An evaluation of the results of the Dynamic Parking Guidance System in Amsterdam showed that 10% of car drivers used the guidance system to find a parking place in the city centre. For these car drivers the number of kilometres driven in and around Amsterdam related to parking decreased by **15%** (0.5 km per car). A survey in Southampton found that drivers reduced the time spent searching for a parking space on average by 50% from 2.2 minutes to 1.1 minutes. A survey of over 600 people in Valencia found that 61% of people were influenced by the information on VMS signs and 30% had changed their parking destination as a result[13].

The **COSMO** project trialled parking guidance at a pilot site at the University of Salerno, Italy. 111 driving tests (58 for a multi storey car park and 53 for an open car park) were performed to measure the time taken to find a space. During each test, the time to travel to reach the car park was

[13] All data from ITS Toolkit www.its-toolkit.eu

measured, as well as the time taken to park (time from entering a car park to finding a free space and parking in it).

The parking guidance comprised advice on free spaces via on-board units (OBUs), a smartphone application and a Variable Message Sign (VMS). A **7%** reduction in fuel and hence CO_2 emissions was calculated for parking vehicles as a result of the reduced time and distance travelled needed to park, when the system was in use.

Intelligent parking is one area where emissions can be reduced by reducing the distance of vehicles circulating while looking for a parking place. While traditional (and widespread) parking guidance using VMS can help, more advanced emerging systems including in-car information offer further potential. In Los Angeles, LADOT and Xerox trialled **LA Express Park**[14], which was a one year demonstration project (June 2012 to May 2013) which aimed to reduce traffic congestion and pollution in the central area of the city through demand-based parking pricing and real-time parking guidance.

The project area covered all of downtown Los Angeles, including 14,000 parking spaces (6300 of them on-street metered spaces and 7700 off-street public parking spaces in nine city-owned car parks). The elements included new parking meter technology, on-street vehicle sensors embedded in the street surface for all parking spaces (to provide real-time occupancy data), off-street occupancy systems, real-time parking guidance, integrated parking management and public outreach. Total cost was US$18.5 million. Parking guidance featured a website, Smartphone applications, on-street dynamic message signs, with in-vehicle navigation systems being planned for the future.

On-street pricing and policies were developed from meter and sensor data using advanced algorithms. Demand-based pricing was introduced in three successive phases: firstly a base hourly plan, using baseline data, iteratively setting base hourly rates to influence demand toward LA Express Park goals.
Phase II, after the second month of operation, identified peak periods and set prices by time of day. Phase III, starting a year later, was adaptive, experimenting with adjusting prices in real-time where demand fluctuates week to week. Pricing was originally $1 to $4 per hour (based on outdated geographical boundaries), whereas under the trial it changed to between $0.50 and $6 per hour (based on a pricing algorithm), with average rates lower in 60% of cases, higher in 27% of cases and unchanged in 13% of cases.

The results, in addition to a 2.4% increase in revenue, led to a reduction of 6% in the number of spaces that are congested (occupied over 90% of the time), an increase of 9% in the number of spaces with optimal occupation rates (between 70% and 90% of the time) and a reduction of 5% of the number of under-utilised spaces (less than 70% occupancy). This more efficient filling of spaces (making under-utilised spaces cheaper, congested ones more expensive, and informing users) led to a

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[14] LADOT & Xerox (2013), presentation entitled "The LA Express Park™ Project: Design, Implementation, and Initial Results", presented at the International Parking Institute Conference and Expo, Fort Lauderdale, USA, May 2013

10% reduction in circulating traffic looking for parking spaces. Los Angeles is continuing to implement time of day pricing and is introducing adaptive pricing based on current demand.

5. Global analysis and conclusions

5.1 Comparative analysis of potential of different ITS applications

Tables 6 and 7 on the following pages compare the main applications covered in this report, for in-vehicle applications and infrastructure applications respectively. They show the absolute ranges for each type of application on relevant road types (where data exists) as well as the overall likely potential (excluding the more extreme results and taking into account penetration and network considerations).

The tables also indicate the Technology Readiness Level (TRL), or levels, of each application. TRL scales are from 0 (idea or unproven concept) to 9 (full commercial application). Different descriptions of each level used by different governmental departments and other organisations, although these are generally consistent with each other and differences mainly relate to the technology domain for which the organisation is responsible, e.g. vehicles, energy systems, aerospace, etc. Table 5 below illustrates an example from the European Commission.

Table 5: Technology Readiness Levels[15]

Technology Readiness Level	Description
TRL 1.	basic principles observed
TRL 2.	technology concept formulated
TRL 3.	experimental proof of concept
TRL 4.	technology validated in lab
TRL 5.	technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6.	technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7.	system prototype demonstration in operational environment
TRL 8.	system complete and qualified
TRL 9.	actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Following the tables, Figure 5 provides a graphical representation of the results of the different studies, indicating the type of network(s) on which they were done, the type of test (on-road, simulation, etc) and the approximate size of the trial (number of runs).

[15] Source: "Technology readiness levels (TRL)" (PDF). European Commission, G. Technology readiness levels (TRL), HORIZON 2020 – Work Programme 2014-2015 General Annexes, Extract from Part 19 - Commission Decision C(2014)4995

Table 6: In-vehicle applications: Comparative analysis

Type of application	Studies considered	Range of CO_2 reduction				Technology Readiness Level (TRL)	Remarks
		Urban streets (<50 km/h)	Suburban or rural roads (60-90 km/h)	Motorways or expressways (>100 km/h)	Overall potential by 2030 (EU-wide, all networks)		
Navigation / Eco-routing	Navteq, ICT-EMISSIONS, euroFOT	3%-12%	3%-19%	3%-25%	Around 10% per equipped vehicle, depending on network characteristics. Overall potential in 2030 (from ICT EMISSIONS) for urban areas only (based on Madrid): 2.3%-6.8% with 25% penetration rate; 3.3%-7.8% with 50% penetration rate; 4.9%-9.4% with 90% penetration rate	TRL 8 to 9 Systems already commercially available, but more accurate and performant systems being developed and trialled.	Less effective in congested networks; benefits fall with higher penetration rates. In peak periods, overall benefits fall when penetration rises above 30% due to network saturation. Lower end of estimation (3% for standard navigation, 4.5% for eco-navigation) identical for all road types because that figure is from a study using a mixture of roads, without distinguishing results per road type.
Driver behaviour/ Eco-driving	eCoMove, RAC, Navteq, ICT-EMISSIONS, HECO2	6%-12.5% (higher where linked to traffic signal status, e.g. 25%)	N/A	5.5%	0% – 35% (typically 5% - 20%) per vehicle. However ICT EMISSIONS model for Madrid for 2030 showed no real benefit at urban level due to reduction in road	TRL 5 to 9 After-market and nomadic systems now commercially available; more accurate and performant integrated systems are at various stages from large scale	Less effective in congested networks as it can reduce road capacity. More effective in urban situations than motorway. HMI type influences results: haptic pedal and Head-up display are more effective; Smartphone

Type of application	Studies considered	Range of CO_2 reduction				Technology Readiness Level (TRL)	Remarks
		Urban streets (<50 km/h)	Suburban or rural roads (60-90 km/h)	Motorways or expressways (>100 km/h)	Overall potential by 2030 (EU-wide, all networks)		
					capacity.	prototype tested in intended environment (TRL 5) to demo system (TRL 7).	applications appear less so
ISA (Intelligent Speed Adaptation)	ISA-UK	0.4%	1.2%	3.4%	0.4% - 3.4% for voluntary ISA (potential up to 5.8% with full compliance, i.e. mandatory ISA)	TRL 7 to 8 Demonstration system operating in operational environment, to first of a kind commercial system (manufacturing issues solved).	Extensive long-term trials in 2 regions in England, with robust validation. ISA in this trial was advisory, hence drivers could ignore/override the recommended speed if they wished
ACC (Adaptive Cruise Control)	ICT-EMISSIONS, euroFOT	2%	N/A	2.1%-9%	Potential in 2030 (ICT EMISSIONS) for urban areas (Turin data): 1.1%-3.7% with 40% penetration rate; 1.3%-7.3% with 60% penetration rate; 2.3%-7.0% with 80% penetration rate 2.2%-10.4% with 100% penetration rate. EU-27 impact modelled by euroFOT for motorways: 0.96% with full penetration.	TRL 5 to 9 ACC commercially available, but more work required for Cooperative ACC. The technology is mature for trucks by using the ADASIS interface and is rolled out now on cars as announced by Daimler for all their vehicles.	Best results on inter-urban roads or highways, with high penetration rate. Lower benefits in urban situations. Benefits greater at medium levels of congestion/traffic flow (2.1%-10.4% CO_2 reduction depending on penetration rate). For congested situations, reductions are less (1.3%-7.9%) and for free-flow, less still (0.1%-2.2%)

Table 7: Infrastructure applications: Comparative analysis

Type of application	Studies considered	Range of CO_2 reduction				Technology Readiness Level (TRL)	Remarks
		Urban streets (<50 km/h)	Suburban or rural roads (60-90 km/h)	Motorways or expressways (>100 km/h)	Overall potential (EU-wide, by 2030)		
UTC – Adaptive Traffic Signal Control	ADAC/TUM,	11%-17%	N/A	N/A	Not measured	TRL 7 to 9 Full commercial application, technology deployed in numerous cities.	
UTC - Traffic Signal Control, green wave	ICT-EMISSIONS	3.3%-7.4% for treated corridors	N/A	N/A	Potential around 5% but only in areas with many traffic lights. Savings overall in urban areas might be half this figure: around 2%-3%.	TRL 7 to 9 Full commercial application, technology deployed in numerous cities.	Better results with driver information (e.g. VMS) giving speed advice needed to ride a green wave. Studies give conflicting results as to whether benefits are greater in congested or uncongested situations. Effects of green waves on pedestrian phases must be considered: if traffic light strategies make walking (or cycling) less convenient or more dangerous, this will have adverse effects.
Traffic Signal Control with i2v comms	eCoMove, Tonji University	3.6%-4.1% (all traffic) 13%-25% for vehicles with i2v comms	N/A	N/A	Average 20% for equipped vehicles in areas with equipped traffic lights. City-wide, with 30% of	TRL 4 to 7	In-vehicle communication is more effective, giving info/ advice tailored to the driver (on speed, status of upcoming traffic light, etc.)

Type of application	Studies considered	Range of CO_2 reduction				Technology Readiness Level (TRL)	Remarks
		Urban streets (<50 km/h)	Suburban or rural roads (60-90 km/h)	Motorways or expressways (>100 km/h)	Overall potential (EU-wide, by 2030)		
					vehicles equipped, CO_2 reduction potential is around 3.5% to 4%		
Parking guidance (VMS)	KonSULT knowledge base, ITS Toolkit	2%-15%	N/A	N/A	Typical 2% figure for urban areas is quoted by KonSULT based on a UK project on Urban Traffic Management and Control (UTMC03, 2000), but highly dependent on parking availability on and off-street. 15% was from a study in Amsterdam and relates to distance savings, although actual average distance saved was only 0.5km.	TRL 9 Full commercial application, technology deployed in numerous cities.	Benefits will be greatest when the demand for off-street parking is approximately equal to supply. If there is an excess demand for off-street spaces, parking guidance is expected to have little impact on the problem, as all signs would tend to show 'no space' without providing an alternative solution to the driver. If demand is sufficiently less than supply and spaces are easy to find, the system provides little benefit.
Parking guidance with i2v comms	COSMO, LA Express Park	7%-10% reduction for cars intending to park	N/A	N/A	The 7%- 10% reduction figure is for traffic trying to park and using the facility, not urban traffic overall. Therefore	TRL 5 to 8 Demonstrations and prototypes up to first real deployment (with drivers receiving info by	Better results with in-vehicle HMI giving parking advice. City-wide benefit depends on proportion of traffic looking to park vs transit traffic or

Type of application	Studies considered	Range of CO_2 reduction				Technology Readiness Level (TRL)	Remarks
		Urban streets (<50 km/h)	Suburban or rural roads (60-90 km/h)	Motorways or expressways (>100 km/h)	Overall potential (EU-wide, by 2030)		
					overall benefit could be around half this figure, depending on local circumstances.	smartphone)	traffic with an already allocated (private) parking space at its destination, as well as on-street parking availability.
VSL (Variable speed limits)	ICT-EMISSIONS	N/A	N/A	1.1%-2.6%	1.1%-2.6% is for individual vehicles on equipped highways, but overall benefits lower as VSL can increase capacity therefore attract higher traffic levels. Overall benefit modelled for entire city of Madrid (for deployment on 1 urban motorway only) for 2030 is 0.1% (in medium congestion) and 0.05% (in heavy congestion)	TRL 9 Full application, deployed on numerous motorways and high speed roads (especially urban expressways)	Generally a measure to increase capacity, reduce congestion and accidents, but some marginal benefits re: emissions. However if they allow greater volumes of traffic to use the road, total emissions could rise.

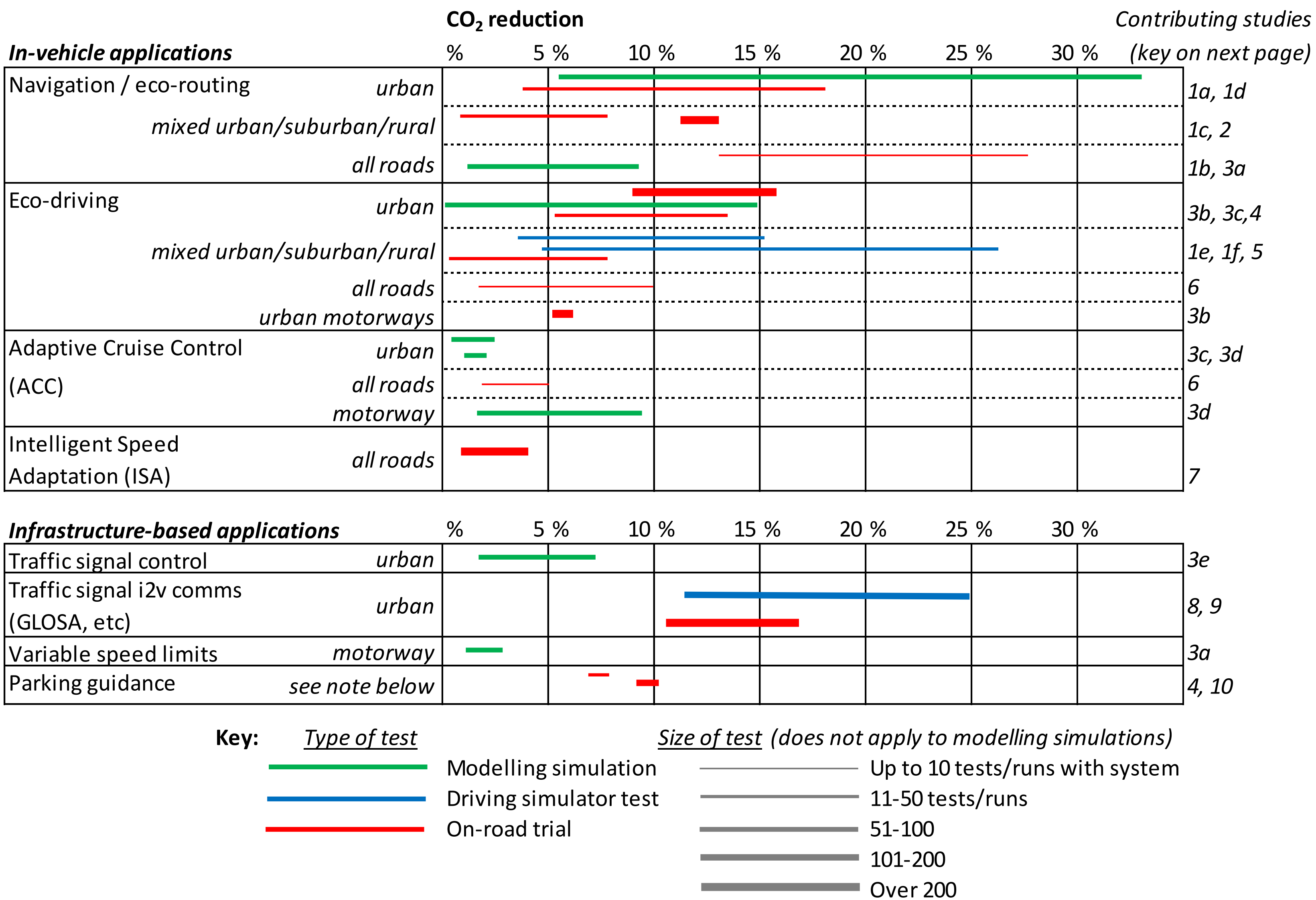

Figure 5: Summary chart for range of effects of applications on different networks

Notes to Figure 5 on previous page:

- Ranges relate to one standard deviation (= approx. 68% of samples assuming a normal distribution) for studies where a standard deviation is given, in order to eliminate extreme values. This is the case for most of the data. In these cases, the mean lies halfway along the line. Where there is no standard deviation given, the range from worst to best is given; the mean is also close to the centre of the line in each case.
- Line colour and thickness indicate the type of test and (for on-road trials and driving simulator tests) the approximate size of the test (based on number of runs made, excluding baseline tests without the system under investigation).

Key to contributing studies in Figure 5 (codes given on the right of the diagram):

1 - eCoMove	1a - Munich modelling simulation
	1b - Munich trial
	1c - Turin trial
	1d - Helmond trial
	1e - ecoADAS driving simulator with HuD, Munich
	1f - Braunschweig eco-driving simulator with haptic pedal
2 - Navteq trial in Düsseldorf and Munich	
3 - ICT EMISSIONS:	3a - Madrid modelling simulation
	3b - Madrid trial
	3c - Turin modelling simulation
	3d - Munich modelling simulation
	3e - Turin and Rome modelling simulation

4 - COSMO trial in Salerno (note the reduction applies only to equipped vehicles intending to use the parking facility, it is not a global reduction)
5 - GERICO (Continental), Munich
6 - HECO2 trials
7 - ISA (UK)
8 - Tonji University driving simulator, Shanghai
9 - ADAC/TUM trials, Munich (results modelled onto different car types)
10 - LA Express Park trial/implementation in Los Angeles (note the reduction applies only to equipped vehicles intending to use the parking facility, it is not a global reduction)
11 – euroFOT.

5.2 Conclusions

Intelligent Transport Systems (ITS), by applying information and communication technologies to vehicles and transport systems, have the potential to make a major contribution to reducing CO_2 emissions if successfully deployed.

Innovative ITS applications and services are the basis of significant improvement of vehicle energy management leading to higher energy efficiency and reduced CO_2 emissions. The keywords are data, prediction and connectivity. ITS brings data and information among the different components of the transport systems and services.

It should be noted that the benefits observed in trials, even large scale ones with reliable and validated data, will not necessarily be the same as that which might be experienced on the road with full roll-out of the system.

Navigation systems have the potential to reduce fuel use in the order of 5%, improving to around 10% where an eco-routing is possible (compared to the fastest route) and when the routing is based on real time information on traffic conditions. There is however considerable variability, in particular in function of the network characteristics (availability of different routes), local knowledge of the driver of alternative routes and changeability in traffic conditions (such that a regular driver on a route could receive a different routing recommendation dependent on the day and time of the journey).

Eco-driving support systems offer probably the greatest potential, offering up to 20% savings in emissions and in some cases over 30%. However results are highly variable in terms of context: road type, vehicle type and transmission system, HMI, traffic fluidity, etc. The extent to which drivers follow advice or keep up eco-driving behaviour, as well as the level of their driving without such systems (baseline performance), is a major uncertainty factor.

Situations with the highest potential were often in urban surroundings (speed limit 50 – 70 km/h) at traffic lights. Especially when approaching a red traffic light which was about to switch to green the information through an eco-driving support system which is capable of communication with the traffic light could lead to great fuel reductions close to, or in some cases above, 20% depending on the recommended target speed.

There is evidence from the Continental project GERICO that haptic pedals are more effective in modifying driver behaviour than a visual HMI alone. Further data on this subject is expected from the ecoDriver project in late 2015.

For some situations, especially at static features like curves, roundabouts and stop signs, there were fewer benefits and drivers were sometimes less likely to follow the driving advice than was the case at traffic lights. The eCoMove project reported that in these cases, drivers sometimes felt that system made them go more slowly than they wanted to. If such situations are to be supported, they would have to avoid making drivers feel frustrated, as this would negatively affect compliance with the advice from the system. Development of an HMI which can motivate the driver, e.g. by displaying the fuel or cash savings being made by their driving behaviour, is crucial to the success of eco-driving ITS applications.

Hence despite the variability in results, eco-driving is a key area for exploration, where ongoing research will further contribute to knowledge on success criteria.

On the infrastructure side, intelligent **traffic signal applications** can achieve notable savings, with most results being in the 3-7% range for established urban traffic control (UTC) with green waves. In-vehicle applications provide greater benefits, typically 15-20% and up to 25%, but the challenge here is to create on-board applications which work with different traffic signal technologies and strategies in different cities and countries. Trials in this area have mostly been small scale, focusing on a specific corridor of a single city. The benefits of traffic signal applications can vary widely in function of aspects such as the density of traffic lights, traffic movement patterns (amount of traffic going straight on at intersections compared to turning movements), traffic signal phases for pedestrians, public transport priority, cycle lanes, etc. The wider implications of intelligent traffic signal control are that it can create extra capacity which then generates additional traffic (either more trips being made or a modal shift towards cars if car journey times or costs become more attractive). These macro aspects are not known to have been studied in any trial.

Intelligent parking can reduce vehicles searching for parking places, thereby reducing traffic (and hence emissions), but there is no reliable evidence of overall percentage reduction, which would depends on parking availability and demand in each case. As for traffic signals, in-vehicle HMI increases the benefits: 7 to 15% reductions in distances travelled looking for parking spaces by users have been reported in studies. However most of these figures are based on limited areas in the vicinity of parking facilities so these reductions are not for the whole trip, only for the parking search part, where in absolute terms this equates to a few hundred metres saving in distance driven per user. The challenge however is one of interoperability among the myriad parking facilities. Again, making parking in cities easier for the driver could lead to greater travel demand or modal shift to the private car.

The most promising infrastructure based applications are therefore at the urban level. For non-urban roads (uncongested suburban networks, interurban main roads and motorways, regional and rural roads), there are no ITS infrastructure applications that can directly reduce the emissions of cars, with the possible exception of **variable speed limit** signs on motorways. However these tend to bring other benefits (reduced congestion, greater capacity, safety and travel time improvements) rather than environmental ones, which are quite limited and can be cancelled out in the event that additional traffic is attracted to the route as a result. Therefore, while very valuable in meeting other objectives, it should not be considered a key enabler for reducing CO_2 emissions.

Finally, in-vehicle systems like **ISA** and **ACC** can provide small benefits, around 3 to 5%. While these figures are relatively low, it should be considered that these systems are primarily safety-oriented and that any CO_2 reduction is a side-benefit but nevertheless a worthwhile one.

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