Supporting the driver in conserving energy and reducing emissions

ecoDriver

D1.6: Final publishable summary report

(Version 1; 12/06/2016)

Subproject	SP0: Project Coordination
Work package	WP1: Project Management
Task	T1.1
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Dissemination level	Public (PU)
Status	Draft
Due date	13/06/2014
File Name	Final publishable summary report 160612.docx

IP Coordinator	Oliver Carsten, University of Leeds
SEVENTH FRAMEWORK PROGRAMME	The research leading to these results has received funding from the European Union Seventh Framework Programme under grant agreement n° 288611. FP7-ICT-2011-7: Information and Communication Technologies Low carbon multi-modal mobility and freight transport

Control sheet

Version history			
Version	**Date**	**Main author**	**Summary of changes**
1	23/03/2016	Oliver Carsten	Template created
2	17/05/2016	Guillaume Saint Pierre	SP4 material
3	18/05/2016	Johan Olstam	SP5 material
4	19/05/2016	Pablo Mejuto	SP3 material
5	23/05/2016	Andrew Winder	Dissemination material
6	31/05/2016	Dennis Kooijman	SP2 material
7	01/06/2016	Rino Brouwer	SP1 material
8	05/06/2016	Oliver Carsten	Cuts to text
9	08/06/2016	Samantha Jamson	Project context
10	10/06/2016	Oliver Carsten	Executive summary
11	12/06/2016	Oliver Carsten	Final edits

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Reviewed by	NA
Authorised by	Oliver Carsten
Verified by	Samantha Jamson

Circulation	
Recipient	**Date of submission**
Project partners	13/06/2016
European Commission	13/06/2016

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Glossary of terms

Term	Description
Eco-driving	Environmentally friendly driving (green driving)
Feedback (advice)	Information about the user's behaviour and performance based on completed actions
Feedforward (advice)	Information about an event that will happen in the near future giving the user the chance to anticipate his actions
Full ecoDriver System (FeDS)	Prototype eco-driving support system developed by ecoDriver and integrated into the vehicle
Naturalistic driving	Tests whereby the driver is free to drive normally, on routes of their choice, as part of their everyday activities (as opposed to controlled studies where fixed routes are mandated). Naturalistic driving is observed unobtrusively and provides insight into driver behaviour in everyday situations. However there is no experimental control in that before and after tests (without the system and with the system) cannot be identical.

Acronyms

Acronym	Description
App	application
BMW	BMW Research and Technology
CAN	Controller Area Network
CO_2	Carbon Dioxide
CRF	Centro Ricerche FIAT S.C.p.A.
CTAG	Fundación para la Promoción de la Automoción en Galicia (Centro Technológico de Automación de Galicia)
DoW	Description of Work
DG Connect	EC Directorate General for Communications Networks, Content & Technology
EC	European Commission
EU	European Union
ESoP	European Statement of Principles on HMI for In-Vehicle Information and Communication Systems
FeDS	Full ecoDriver System

Acronym	Description
FESTA	Field Operational Test and Support Action
FEV	Fully Electric Vehicle
FOT	Field Operational Test
ftp	File transfer protocol
GPS	Global Positioning System
HMI	Human-Machine Interface
HuD	Head-Up Display
ICE	Internal Combustion Engine
IFSTTAR	Institut Français des Sciences et Technologies des Transport, de l'Aménagement et des Réseaux (French Institute for Science and Technology for Transport, Development and Networks)
IKA	Institut für Kraftfahrzeuge of RWTH Aachen University
IVIS	In-Vehicle Information System
LCV	Light Commercial Vehicle
NOx	Nitric oxide
OEM	Original Equipment Manufacturer
PI	Performance Indicator
Rpm	Revolutions per minute
SP	Sub-Project
TNO	Nederlandse Organisatie voor Toegepast-Natuurwetenschappelijk Onderzoek (Netherlands Organisation for Applied Scientific Research)
UNIVLEEDS	University of Leeds (Institute for Transport Studies)
VMC	Vehicle Management Centre (ecoDriver partner test site)
VTI	Statens väg- och transportforskningsinstitut (Swedish National Road and Transport Research Institute)
WP	Work Package

Acknowledgements

Many people contributed to the successful outcome of the project. We would like to thank the following for their contribution to the ecoDriver project:

Dennis Huang, Jan Loewenau (BMW)

Cristina Barberi, Laura Borgarello, Roberto Brignolo, Paolo Capano, Alessandro Iviglia, Antonella Masala, Manola Mazza, Antonella Toffetti (CRF)

Rosa Blanco, Luis Conde, Oscar Dias, Eva García, Rubén Gómez, Pilar González, Moisés Rial Martínez, Abel Nogueira, Samuel Rios, David Sanchez, Ángel Soto (CTAG)

Mario Aleksic, Alexander Bracht, Roland Trauter, Michael Henzler (Daimler)

Silvia Curbelo, Lise Goudeseune, Jean-Charles Pandazis, Nuno Quental, Amanda Strevens (ERTICO)

Cyndie Andrieu, Qi Cheng, Lydie Nouveliere, Olivier Orfila (IFSTTAR)

Johanna Josten, Steffen Schneider, Philipp Seewald, Philipp Themann, Adrian Zlocki (IKA)

Davy Bijnen, Jenny de Boer, Tineke Hof, Jeroen Hogema, Thomas Ivens, Eline Jonkers, Bart Kappe, John Kessels, Gerdien Klunder, Liselotte Kroon, Ouren Kuiper, Norbert Ligterink, Martijn van Noort, Coen Obdeijn, Geerte Paradies, Stefan Spronkmans, Arjan Stuiver, Caroline van der Weerdt, Remco Wijn, Zeriet Woldeab, Isabel Wilmink (TNO)

Jasper Pauwelussen, Gianfranco Santoro (TomTom)

Christer Ahlström, Viktor Bernhardsson, Carina Fors, Jonas Ihlström, Katja Kircher, Johan Olstam, Jonna Nyberg, , Andreas Tapani (VTI)

Richard Batley, Charisma Choudhury, Astrid Gühnemann, Susan Illingworth, Hamish Jamson, Ann Jopson, Daryl Hibberd, Frank Lai, Tyron Louw, Natasha Merat, John Nellthorp, Reto Tanner, James Tate (UNIVLEEDS)

In addition, we would like to extend our thanks to the technical teams involved at all stages of the project and the participants who took part in the user trials.

1. Executive summary

ecoDriver has addressed the need to consider the human element when encouraging “green” driving, since driver behaviour is a critical element in energy efficiency. The focus of the project has been on technology working with the driver. It developed a set of advice and feedback solutions, providing preview of upcoming events, advising the driver on how to save energy in the current situation and providing feedback on performance both in drive and post drive. A model for the real-time optimisation of energy use was developed to ensure the accuracy and appropriateness of the advice given.

Systems were developed, installed and trialled on a wide range of vehicles cars, light trucks and vans, heavy trucks and buses. Those systems varied from relatively simple and low cost (an Android app) to more elaborate and sophisticated, and included both aftermarket fitments and vehicle manufacturer designs. The systems covered a variety of powertrains — petrol, diesel, hybrid and full electric. One of the systems developed and tested was the Full ecoDriver System (FeDs), which was intended as an exemplar of the project HMI designs and energy calculation software, linked to a full set of sensors.

The real-world trials of the various ecoDriver systems revealed that:

- The project had created an effective HMI design which secured good driver compliance while maintaining attention to the road and traffic
- Energy calculation performs better and produced better advice to the driver if it has access to real-time vehicle-based information
- In the FeDS, the project created a highly capable energy calculator that can assimilate a large quantity of information and recalculate fast, but the vehicle manufacturers have an in-built advantage here in terms of their extra knowledge
- In terms of observed driver behaviour, the systems secured good compliance and produced significant energy savings, as well as substantial improvements in speed compliance, with predicted large safety benefits. The more sophisticated systems tended to encourage greater savings in energy. Overall reduction in observed energy use averaged 4.2% with a higher impact of 5.8% on rural roads. In terms of speed, there were reductions of up to 4% in cruising speed and on the approach to events such as sharp curves. There was an additional effect from providing feedback via a haptic throttle.

A substantial effort in the project was devoted to exploring the wider impacts of the systems on traffic and the environment under a range of scenarios of the future. This allowed the calculation of the costs and benefits of the systems. That modelling of impacts revealed that:

- Widely deployed, the project’s systems could make a real contribution to CO_2 targets for transport
- There would be substantial impact in terms of saved fatalities and injuries as a result of the observed changes in vehicle speed
- The benefit-to-cost ratios of adoption of the systems are excellent
- There is a need for the relevant authorities to promote these systems, if they are serious about achieving their environmental targets

2. Project context and objectives

Under the Europe 2020 initiative, the EU has set a target of a 20% reduction in carbon emissions as compared to 1990 levels to be achieved by 2020. An even more strenuous 30% reduction has also been envisaged "if other developed countries make similar commitments" and if developing countries make appropriate contributions. A subsidiary part of this target is moving towards a 20% increase in energy efficiency and innovative technological solutions are proposed as a contributor.

Road transport currently contributes around 20% of total European carbon emissions. There are ambitious targets strategies to increase the fuel efficiency of new vehicles, with new forms of powertrain such as hybrid and electric vehicles being a major contributor. Regardless of the rate of introduction of such new powertrains, there will be a substantial need for improved energy efficiency of traditional powertrains. With new types of vehicle too, there will be a need to maximise efficiency — so as to, for example, reduce range anxiety among users of electric vehicles. Thus systems to support the driver in driving in an energy-efficient manner should have an important role in reducing unnecessary energy use.

The starting situation for ecoDriver was:

- Existing feedback seems to yield energy savings in the range of 5–10%
- The appropriateness of advice on how to save energy, delivered by many systems especially after-market ones, is unknown
- The advice does not usually consider the upcoming road alignment
- Acceptance of the systems and of the advice given is not known
- Compliance with advice may not be very high
- The acceptance and impact of post-drive feedback is not known
- Side effects, particularly in the potential for distraction of visual attention from the road scene, had barely been investigated.

An open question for the project was how far nomadic systems can be improved in terms of quality of advice, and how drivers would behave when using such improved devices as compared with usage of a fully integrated system. So a major research question for ecoDriver was "How effective are good nomadic systems as compared to integrated systems?"

The global aim of ecoDriver has been to deliver the most effective feedback to drivers on "green" driving by optimising the driver-powertrain-environment feedback loop.
ecoDriver focused on the link with the driver who is the most crucial element in securing compliance with an advisory vehicle-based system. The project had a number of aims and a set of measurable objectives.

The detailed aims of ecoDriver were to:

1. Investigate how best to win the support of the driver to obtain the most energy-efficient driving style for best energy use, covering preview, the current situation and post-drive feedback and learning
2. Assess this across a wide range of vehicles — e.g. cars, vans, light and heavy trucks and buses – covering both individual and collective transport
3. Explore and evaluate alternative HMIs and styles of feedback
4. Consider driver behaviour with a wide range of current and future powertrains, including internal combustion (both petrol and diesel), hybrid and electric, and provide the optimum advice for each powertrain
5. Consider driver style, driver learning and consider how the systems can affect driving style
6. Look at the impacts of eco-driving support on driver attention and safety
7. Look at a variety of impacts: with a focus on CO_2 emissions
8. Consider how the observed effects on driving style would affect network-wide energy use and a variety of aspects of network performance including network efficiency
9. Consider scenarios for future powertrain adoption, and how eco-driving might affect the road networks of the future
10. Perform a cost benefit analysis considering a range of scenarios of powertrain adoption

The specific, measurable objectives of ecoDriver were to:

1. Optimise feedback to drivers for both nomadic devices and built-in systems and compare the effectiveness of each (measured by reduced energy consumption as compared with an existing baseline system). In addition aftermarket systems for trucks and buses were designed, tested and evaluated.
2. Improve driver acceptance by adapting feedback style to a variety of drivers (measured by higher acceptance on subjective questionnaires collected in SP1 and SP3)
3. Minimise any side-effects of eco-driving support in terms of impacts on driver attention and safety (measured by visual allocation and other indicators of attention as measured in the experimental work in SP1 and the evaluation conducted in SP4)
4. Use optimised real-time fuel use models so that the feedback to drivers is as accurate as possible (measured by calibration with off-line models in SP2)
5. Aim for a sustained 20% reduction in energy use (measured in real-world driving across a range of vehicles, assessed in SP4 and further extrapolated in SP5)

Thus the major focus of ecoDriver has been on driver interaction with the vehicle and on optimising support and feedback to the drivers so as to obtain the maximum acceptance and compliance with green driving advice. Support has been provided to drivers both in driving and post-drive. Feedback modalities are important for improving driver comprehension and compliance and therefore the HMI design has been a crucial element. Ensuring that there are no negative side effects in terms of distraction has been an important design consideration.

However technical aspects of systems are critical elements in the loop between vehicle, system and driver. It is vital that the advice given to drivers is based on real-time analysis that is as sophisticated and accurate as possible. Therefore the project developed on-line calculation engines that provide the ecoDriver system with an accurate assessment of how energy-efficient current and previous behaviour is, as well as look-ahead functionality so as to be able to advise the driver how to behave in view of upcoming road situations such as gradients and curves. The calculation engines were adapted for the various types of powertrain (internal combustion engine, hybrid and electric vehicles), the variety of vehicles and the type of device (integrated, aftermarket and nomadic).

The project was organised into five sub-projects (SPs) as shown in Figure 1, with an additional sub-project SP0 covering management aspects. SP1 and SP2 developed the variants of the ecoDriver system, which were deployed by SP3 and evaluated by SP4. SP5 calculated impacts at a European level for a number of future scenarios, i.e. alternative futures.

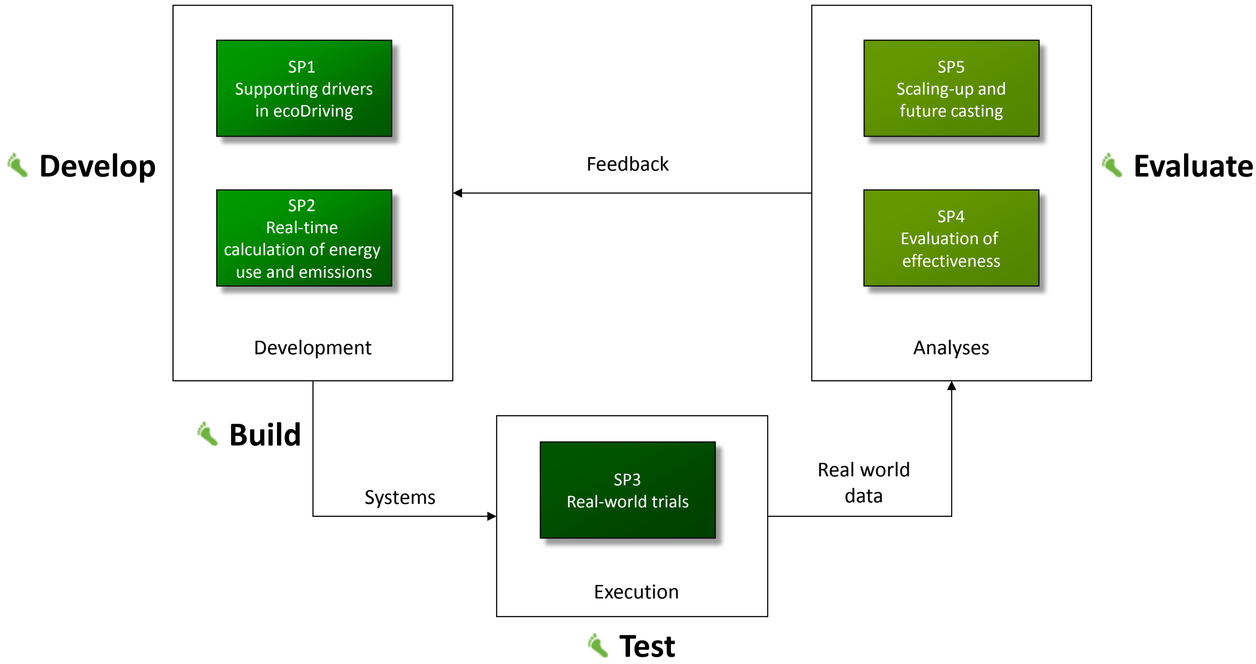


Figure 1: Work structure of ecoDriver

3. Main science and technology results/foregrounds

3.1 How should we present advice to the driver?

SP1 was responsible for the development of the HMIs to be used in the project and also for the system integration, particularly of the Full ecoDriver System (FeDS), which was developed as the exemplar system wholly under the control of the project. In the FeDS, the HMIs of SP1 were integrated with the energy consumption models developed in SP2.

There were three themes to the work: preparation; testing; and system development. The *preparation* work used literature research, user interviews and rapid prototyping experiments to investigate how best to present which information and when, i.e. to develop Feedback and Advice Strategies (FAS). Subsequently, a substantial number of experiments were performed to *test* different features of a system (e.g., providing feedback vs. advice, when to provide information, etc.). The *system development* work had two phases: initially, the systems were developed for the real-world trials; then, following the trials, the systems were updated based on the results of those trials and the updated systems were installed in the vehicles demonstrated at the final event.

The preparation included a review of the state of the art with respect to HMI in eco-driving, on behaviour change strategies, on power trains and on existing eco-driving support systems. We conducted interviews with users and non-users of eco-driving support systems (different kind of drivers (cars, trucks, buses) and fleet owners. We developed storyboards and use cases both for dissemination purposes and for the interviews. We also performed rapid prototyping experiments to investigate the effects of using different modalities to present information to the driver. These activities showed among other results the need to provide explanation for the eco-driving advice/performance, the good performance of haptic guidance through the throttle to the advised eco speed, and the potential benefits of personalised advice and feedback on eco-driving.

The task of developing the HMIs was complex. We created a taskforce to manage the work, and assigned specific research topics to the various partners involved. The list of topics is shown in Table 1.

Table 1: HMI research topics

RT#	Research Topic	Partner
1	Goal setting	CTAG, TOMTOM
2	Detecting driver types	TNO
3	Timing of feedback	CTAG
4	Timing of feed-forward	IKA, DAIMLER
5	Frequency of feedback	UNIVLEEDS[1]

[1] Inherent in RT18

RT#	Research Topic	Partner
6	Frequency of feed-forward	UNIVLEEDS[1]
7	How to present feed-forward	UNIVLEEDS, IKA, BMW
8	How to present feedback and advice	CRF, BMW
9	Complexity of information	CRF
10	Personalised feedback and advice strategies	TNO, CRF
11	Continuous vs. event based visual feedback vs. user induced	VTI
12	Feedback and advice Strategies	CTAG
13	Navigation and eco-driving	IFSTTAR
14	Efficacy of haptic feedback	UNIVLEEDS
15	Knowledge about reason of feed-forward advice (Part of RT7)	IKA
16	Influence of other traffic on eco-driving behaviour	IKA
17	Saving money vs. saving environment (part of RT8)	CRF, TOMTOM
18	Learning transfer of feed-forward and feedback advice (RT5, 6 & 15)	UNIVLEEDS, TOMTOM
19	Presentation of pre-trip features	TOMTOM
20	Information about upcoming trip	TOMTOM
21	Presentation of post-trip features	TOMTOM

These research topics were translated into hypotheses, experimental designs and scenarios. The implications of the experiments for the design of the systems are presented in Table 2.

Table 2: Implications of experiments for system design

Experiment	RT#	Main results	System implications

Learning and transfer of eco-driving advice (ITS Leeds)	5, 6, 7,14, 18	- Do drivers learn to eco-drive at different rates depending on the type of system?
		  - A system is better than no system
		  - Overall, haptic force was more effective
		  - No effect of repetition → no learning at different rates
		- Do drivers prioritise safety over eco-driving?
		  - Yes they do. Also with a visual system
		- Can drivers transfer their eco-driving skills to a new situation?
		  - No they can't
		- Workload / acceptance:
		  - Higher workload and acceptance with visual system
			- Haptic force feedback in CRF system combined with visual information
			- Haptic pedal in Daimler truck for deceleration scenarios
			- All systems: continuous information
			

Driver type detection (TNO)	2	- Good identification of learning/performance oriented drivers. - For some drivers prediction of social / sportive was incorrect	- Although this development is promising and we were able to distinguish certain types of driver the outcomes are not convincing enough (and the technology not robust enough) to introduce this into the systems

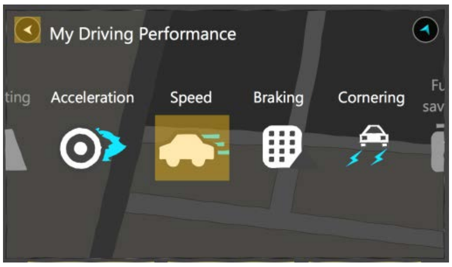
Driver type detection and feedback strategies (TNO)	10	- Compliance was higher with adapted systems
		- Performance-oriented did not like 'learning'
		- Learning-oriented preferred any adapted system
			- Adapting the HMI to a driver type has shown to increase acceptance and compliance
			- The FeDS is a learning oriented HMI, therefore:
			  - Learning-oriented higher preference for the FeDS
			  - Performance-oriented no preference or preference for basic system
			- Given the long and technical complex development of the FeDS, no adaptive HMI is programmed.[2]

[2] Leeds and TNO are investigating the possibility to perform a driving simulator study on adaptive HMI within ecoDriver.

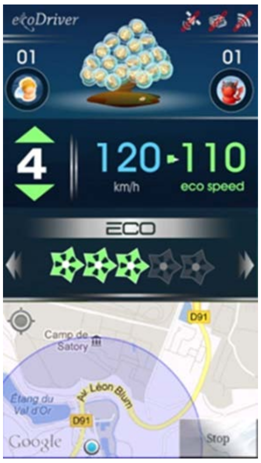
Experiment	RT#	Main results	System implications
Continuous vs. Intermittent Presentation of Visual Eco-driving Advice (VTI)	11	- Drivers adapt their glance behaviour to traffic demand - Systems need to be adaptable to drivers' preferences - Intermittent information is recommended over continuous information as it leads to shorter dwell times	- Combined the intermittent screen with the continuous screen - Most popular items are included 

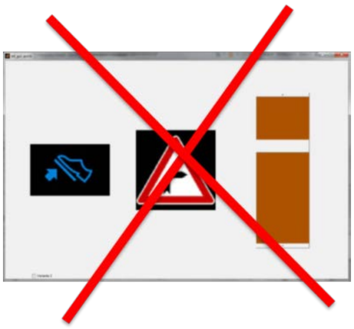
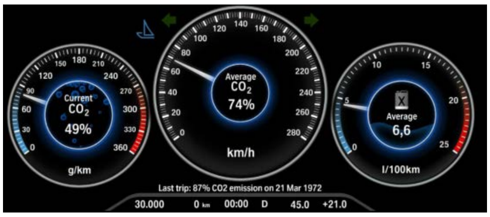
Feedback timing, goal setting and advice strategies (CTAG)	1, 3, 12	- The goal setting factor had no influence
		  - (but other studies indicated its importance)
		- No clear effect for feedback/advice or timing
		  - (Feedback is more effective with a shorter delay based on stars compared to advice which was text-based)
		- Subjective results:
		  - Clearly distinguishable icons
		  - Auditory prompts with information
		  - Feed forward information should be presented more than 110 m before the event
		  - Text should be very short
			- Use advice for specific situations and events, Use feedback for quality of performance, especially after events.
			- Clear icons / no or short text
			

Experiment	RT#	Main results	System implications

Commercial drivers' attitudes to eco-driving advice (TomTom)	1, 17, 18, 19, 20, 21	- Regarding the pre-trip phase:
		  - Motivation to drive in a eco-friendly manner is reducing fuel costs and competition (*gamification*)
		  - Goal setting appreciated
		  - Personalized advice messages
		  - Configurability (message frequency, on/off, sound, etc.)
		- In-trip phase:
		  - Continuous and intermittent feedback get positive ratings
		  - Automatic advice/trip performance summary while standing still or during long periods on highways
		- Post-trip phase:
		  - Drivers like statistics on trip performance
		  - Highlights, with the possibility to go into details, at the end of each trip
			- Goal setting introduced
			- Detailed post trip information
			
			
			

Predictive Coasting Advice (IKA)	4, 7	- Knowledge about the upcoming situation has a positive effect - No effect of social pressure - Long coasting system was more effective (but less accepted)	- Include reason for coasting - Don't start coasting too early (at 70 km/h from 350 m) 

Experiment	RT#	Main results	System implications
Visual vs. haptic interfaces (CRF)	8, 9, 10, 17,	- Haptic solution helps to keep a more ecological driving style - Visual feedback is very important to understand the haptic information - Users like HMI visual feedbacks and think graphic suggestions are helpful in reducing consumption levels - Users would like to have a general score, advice/feedforward information (e.g. curve, roundabout etc.) and a feedback related to performed actions - Users don't want too much information while driving, while with stationary vehicle, a summary screen (acceleration, deceleration, gear and speed scores) would be useful and not invasive	- Haptic and visual - Overall score - Advice and feedback - Detailed information when possible 
Android ecoDriver Application (IFSTTAR)	13	- The map feature induces complexity but more heterogeneous responses - Some people like the map very much, while others seem cautious about it - Frequent users of navigation services like the map feature of the ecoDriver application - Without the map, the application is less often disliked but also perceived as less useful	- The map will be available as an option (in the smartphone) 

Experiment	RT#	Main results	System implications
Presentation of feedforward information (DAIMLER)	4	Motivate coasting advice as reason not always visible to the driver (too far away) • Pre-notice appreciated, but could lead to acting too early • Complaints about messages perceived as not "logical" (e. g. coasting advice when vehicle already coasting)	• No pre-notice as it does not give any additional benefit (and avoids visual clutter) • Look-ahead time for algorithm increased to avoid instances in which the driver is coasting already when the coasting advice is given 
Coasting behaviour and visual feedback (IKA and BMW)	7, 8	• Full system got best ratings • Generally drivers complied with the system • Additional colour feedback does not improve reaction times	• Coasting advice included, colouring not relevant • Full system information improves green driving, but too much detail should be avoided 

Based on this experimental research and the information collected earlier, ten systems were developed and tested in the real-world trials. They are depicted below in section 3.3.1.

The results of the real-world trials and especially the comments provided by the drivers were used to update systems where required. For example, for the Full ecoDriver System (FeDS) the speed advice provided was smoothened and the HMI was adjusted as shown in Figure 1. Various other feedback from the drivers on the HMI, the logic of the systems and the behaviour of the systems led to other adjustments that were incorporated in the vehicles demonstrated at the Final Event.

Figure 2: Final version of the HMI for the FeDs

One of the developments that was not fully carried through was the personalisation (although CRF did develop different systems and tested these in a within-subject design). Although the research performed by TNO was promising, it was not mature enough to be tested under real-world conditions. This applies both to the driver type detection module that tried to relate in real-time driving behaviour to driver personality and the HMI for different driver types. Personalisation, however, is required. Different types of drivers (either segmented by personality or skill) need to learn how to eco-drive. This means that feedback and advice need to target the situations in which drivers show poor eco-driving. In the current systems, the drivers always got advice and feedback. Results of an experiment performed by the University of Leeds showed that drivers could not transfer their eco-driving skills to new situations in which no advice was provided.[3] Thus new situations require new feedback and advice strategies and one cannot rely on learning and retention. A balance then needs to be found as to when to provide advice and feedback and to whom.

Although all the systems looked and acted differently, they had a number of features in common. They all provided performance indications (how well you eco-drove), advice on what to do and why, and speed advice. It is relevant that different systems have a number of features in common so that drivers can be better supported in the transfer of their skills between different types of vehicles.

Another aspect of personalisation is the willingness of people to change their behaviour. The current developed systems target an group of drivers that are willing to change their behaviour and learn to eco-drive. Note that also these people will not always follow the eco-driving rules. Recent work by Hof and Kroon (paper submitted) has indicated that there is a group of drivers who do not care about eco-driving and seem to be insensitive to any kind of intervention to change their behaviour. For these drivers other approaches have to be pursued than the systems developed within ecoDriver.

[3] Under the experimental conditions used.

3.2 How to calculate the best eco-driving advice?

3.2.1 Overall approach

Eco-driving support systems can aid drivers operating their vehicle to achieve higher overall efficiency, and assist them in anticipating upcoming events. Four of these eco-driving support system approaches were developed within the project. These systems, although they all share the same overall ecoDriver architecture, have a different implementation depending on the available sensors on the targeted vehicles, available (online) vehicle information and constraints on the implementation.

The overall architecture can be seen in Figure 1, and consists of three key modules. The first module keeps track of what is going on with, and around the vehicle. The second module decides or calculates what the driver should do to drive safely and ecologically. The third module is the HMI which presents the advice as efficient as possible to the driver. However, a driver will never be able to follow the advice perfectly, and the driving situations can change rapidly. The loop as shown in Figure 1 will therefore run continuously to always give the best advice when the situation changes.

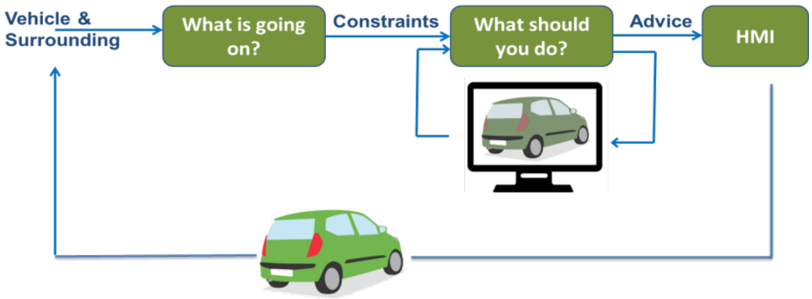


Figure 3: Overall ecoDriver architecture

The "*What is going on*" module is developed as the Vehicle Energy and Environment Estimator (VE^3), and the "*What should you do*" module is developed as the Reference Signal Generator (RSG), although not all system implementations have this clear division between the modules. Figure 2 shows the system with all modules, sensors and sources of information like the CAN-bus, and Map data (via ADAS-RP or Open Street Maps).

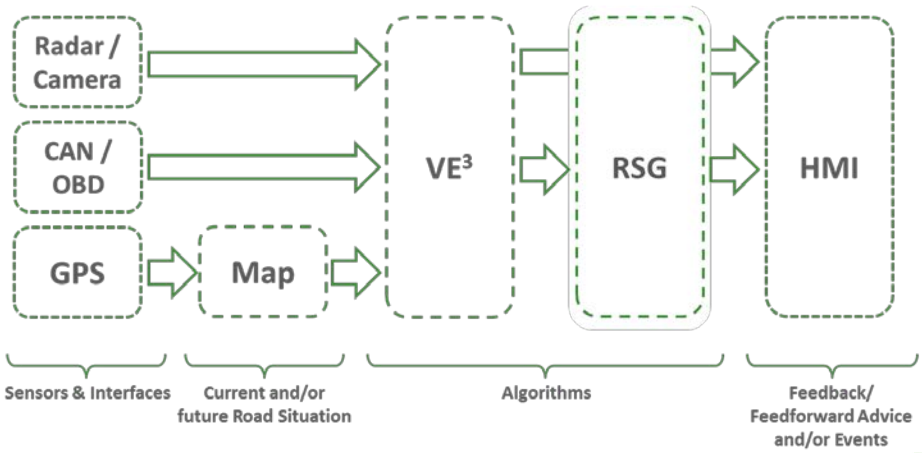


Figure 4: ecoDriver system - full configuration, with all possible modules and sensors. Some systems only have a sub-set of these modules and sensors.

Vehicle Energy and Environment Estimator

The environment around the vehicle has a large influence on the preferred behaviour of the ego-vehicle. Depending on the situation, the actions to be taken can be very different. The Environment Estimation aims to form a snapshot of the environment in such way that the Reference Signal Generator is able to use this information for providing feasible advice to the driver. In general, the approach is to obtain constraints from the snapshot: indications for the boundaries posed by the environment. The underlying algorithms for the estimators rely on available vehicle sensors (e.g. camera and radar) and enhance their estimate with information from satnav systems where after sensor and map information are merged and interpreted. The environment estimation also takes into account safety factors, such as cornering speed and distance to preceding vehicle (if this information is present). It is in its most complete form built up from on-line algorithms to estimate characteristics of the vehicle environment (speed limiting road elements) which have an impact on energy consumption and emissions, augmented with powertrain models for some of the systems.

Reference Signal Generator

The RSG takes into account both elements provided by the VE^3: the energy consumption estimation and the environment estimation. These can be used both for past and future advice, which is considered to be feedback and feed-forward, respectively. Based on this knowledge, optimisation algorithms that calculate the optimal reference guidance signals have been developed. This information is then passed to the HMI application, giving driver guidance. How this optimisation is done differs per system, and as a result, also the type of advice.

For the Full ecoDriver System for example, a model predictive based optimisation is performed over multiple paths within the feasible domain provided by the VE^3. As a result, a speed advice can be given from a certain initial speed until a targeted end-speed, utilising the most efficient working points of the powertrain. Systems comparing Key Performance Indices target the end-(green) speed directly.

3.2.2 Overview of system differences

Table 3 describes the most important differences among the ecoDriver systems in terms of:

1. Constraints: the RSG can either be specifically for one vehicle (because of vehicle model) or have a generic character.
2. How the Reference Signal Generation works: this can be a model- or rule-based energy consumption optimisation (for different scenarios) or performance indicators, which are derived from the driver behaviour.
3. Main Advice type: the feed-forward information (advice for the near future) can either be presented as a speed advice or as an event (e.g. “start coasting now”).

Table 3: System differences

	VE³		RSG		HMI	
	Constraints	**Dynamic constraints**	**Models**	**Optimisation**	**Main advice type**	**Generic System?**
Full ecoDriver System	Legal Speed Limits, Curves, Slopes, Intersections	Predecessor, and traffic light prepared	Detailed vehicle model	Model based energy optimisation	Speed Incl. events	No
Nomadic ecoDriver System	Legal Speed Limits, Curves, Slopes, Intersections	None	Basic	Performance indicators	Speed Incl. events	No
OEM system	Legal Speed Limits, Curves, Slopes, Intersections	None	Basic	Rule & Model Based	Coasting (Event)	No
TOMTOM system	Legal Speed Limits, Curves, Slopes, Intersections	Traffic jams	Data collection	Performance indicators	Coasting (Event) & Green speed (Event)	Yes

Constraints set

All systems deal with intersections, road grade, road curvature and speed limits.

Dynamic constraints

Most speed limiting road elements are found at a fixed position on the vehicle's route. However, for dynamic constraints such as preceding vehicles and traffic lights, this is different: they pose a constraint to the vehicles trajectory both in time and distance. The FeDS is able to handle constraints expressed both in time and position and is therefore able to deal with traffic light switching as well. Traffic light functionality was however not enabled during the tests.

Vehicle model

Most systems use a vehicle model, some more advanced than others. TomTom uses, amongst other sources, the derived fuel use data from the CAN-bus to calculate a driving advice.

Reference velocity versus event-based feed-forward

Three of the four systems have event-based feed-forward advice: when an event is triggered in the near horizon and it is important to adjust the velocity, an advice event is provided. The FeDS however, continuously provides advice. This is based on the electronic horizon from the VE³ plus RSG and is always starting from the current position and velocity. If a major change in the continuous advice is expected, an advice event is additionally triggered, in order to draw the attention of the driver.

3.3 Overview of on-road trials

The objective of the on-road trials was to test the developments performed in the ecoDriver project in real conditions to check the performance of the 6 ecoDriver systems. The real scenarios where these systems were tested was a clear advantage to get the most real feedback from the participants and the most reliable data collected for the analysis and conclusions of the performance achieved with the developments. These tests were executed with a selection of more than 200 drivers, in 7 countries, from the North to the South of Europe and from East to West, and with more than 60 vehicles. These means that a wide set of variables, including social, powertrains and roads aspects were taken into account.

3.3.1 Systems tested

During the 24 months of the trials the following systems were tested:

1. **FeDS (Full ecoDriver System)**
   This provided green speed and gear, (for manual shift vehicles) event-based advice and feedback.

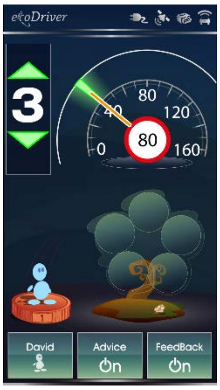


Figure 5: FeDS (Full ecoDriver System)

2. **OEM: BMW ecoDriver System**
   This system includes an auto-coasting gearbox and a HUD (Head Up Display).

Figure 6: BMW ecoDriver system

3. **OEM: CRF ecoDriver system**
   There were three different HMI designs, for the three different vehicles, one on the Alfa Romeo Giulietta with the option of a haptic pedal to improve the feedback to the driver.

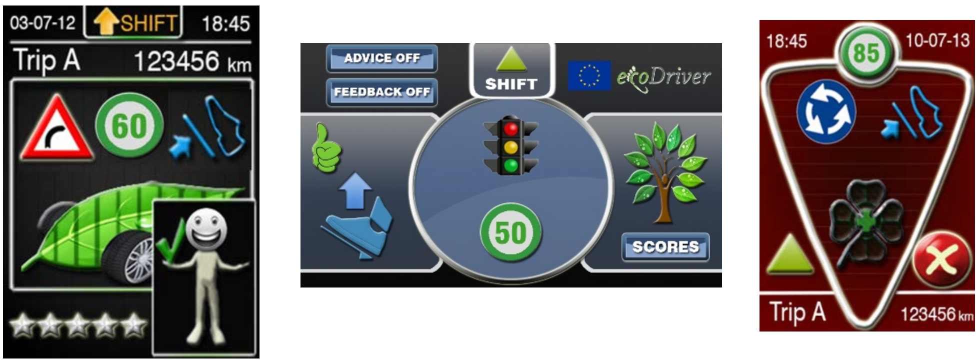


Figure 7: CRF ecoDriver system

4. OEM: Daimler ecoDriver system

This was designed for a truck and included a haptic pedal.

Figure 8: Daimler ecoDriver System

5. OEM: TomTom ecoDriver system

This was developed on a TomTom device platform enriched with ecoDriver features.

Figure 9: TomTom ecoDriver System

6. Nomadic ecoDriver System

This was based on the FeDS design with basic but complete functions to be used in any car as a plug and play system.

Figure 10: Nomadic ecoDriver System

3.3.2 Test sites

The systems introduced above were tested in nine different test sites distributed across seven different countries in line with the locations of the ecoDriver partners involved in these trials. Figure 10 shows the distribution around Europe of the Vehicle Management Centres (VMCs) where the trials were performed. Table 4 summarises the main characteristics of the test sites and routes driven during the trials.

Figure 11: Distribution of ecoDriver trials across Europe

Table 4: Trial characteristics by VMC

VMC/Partner	Test Site	Characteristics

CTAG	Spain	• Urban: 10km
		• Rural: 14 km
		• Interurban: 14 km
		• Motorway:22km
		• Hilly and flat roads
		• Systems tested: FeDS and Nomadic ecoDriver System
		• Vehicles:
		    • FeDS: Renault Scenic and Nissan Leaf
		    • Nomadic: Fleet of 10 different vehicles

IFSTTAR	France	• Dense urban, interurban, motorway • 25 km • Vehicle: Renault Clio • System Tested: ecoDriver Nomadic System

VMC/Partner	Test Site	Characteristics
IKA	Germany	• Balanced Route: 45 km (Rural, Urban, Highway) • Vehicle: VW Passat • System Tested: FeDS
DAIMLER	Germany	• Route: Stuttgart- Esslingen-Münsingen – Stuttgart • City, Highway, Rural, hilly, 263 km • Vehicle: Truck Mercedes Actros • System tested: OEM Daimler ecoDriver System
BMW	Germany	• 11km city • 28 km motorway • 27km country roads • System Tested: OEM BMW ecoDriver System • Vehicle: BMW 5 Series
TomTom	Germany	• Vehicles: LCVs (MB, Ford, Renault) • Free route • System tested: OEM TomTom ecoDriver System
	The Netherlands	• Vehicles: LCVs (Fiat, MB, VW) and Truck (MB) • Free route • System tested: OEM TomTom ecoDriver System
CRF	Italy	• Rural, Urban and motorway • 52 km • Vehicles: Lancia Musa, Fiat Bravo and Alfa Romeo Giulietta • System tested: OEM CRF ecoDriver System (3 different versions)
VTI	Sweden	• Route: urban, rural and motorway • 90 km • Vehicle: Volvo V40 • System tested: FeDS
University of Leeds	UK	• 10 Hybrid Bus • Route: urban environment • 11km • System tested: OEM TomTom System

3.3.3 Data collection and treatment

The main purpose of the trials was to collect data to be analysed, take conclusions about the performance of the systems designed and developed and check against the objectives of the project. The data collected during the trials came from three different main sources as shown in Figure 11.

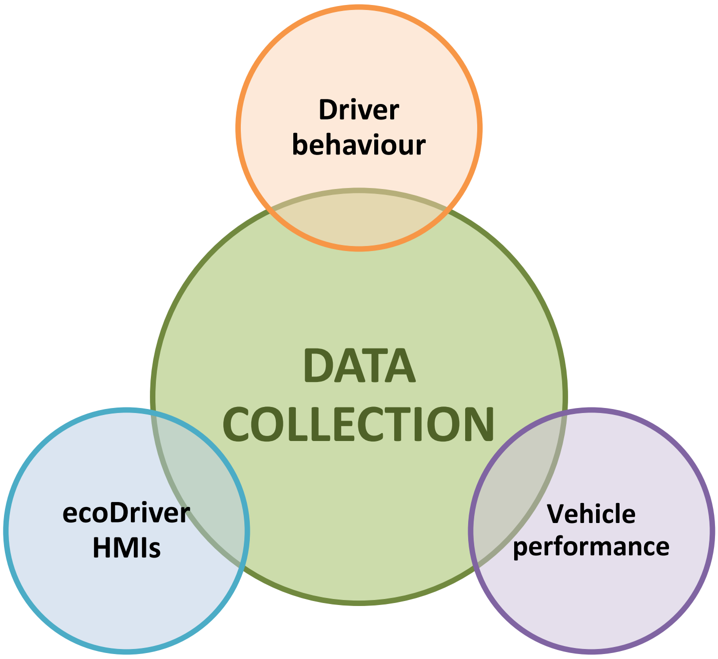


Figure 12: Sources of data collection

The collection of data from these three different sources ensured that any action, status or was logged for an easy understanding of the context and scenario during the analysis. Below is a short description about what is logged from these sources:

1. Driver behaviour

This data was collected with a tablet application developed in the ecoDriver project during the controlled studies, where an observer was in the car during the test, taking notes about driver behaviour.

2. ecoDriver HMIs

The information displayed on the HMIs displays was logged to provide information about the content of recommendations given to the driver and when these occurred.

3. Vehicle performance

The information available in the CAN bus of the vehicles was logged so as to know the status and use of the vehicle powertrain.

The data collected was stored in a central server where different processes were applied before the analysis. The objectives of this data treatment process were to:

- Lose or discard the least amount of data possible for poor quality or corruption
- Check the veracity and coherence of the data collected
- Enrich the data collected with high-quality data from external sources (map database) and fusing the data collected
- Provide the highest quality data and the largest amount of data possible for the subsequent analysis

Figure 12 provides a description of the processes applied to the data.

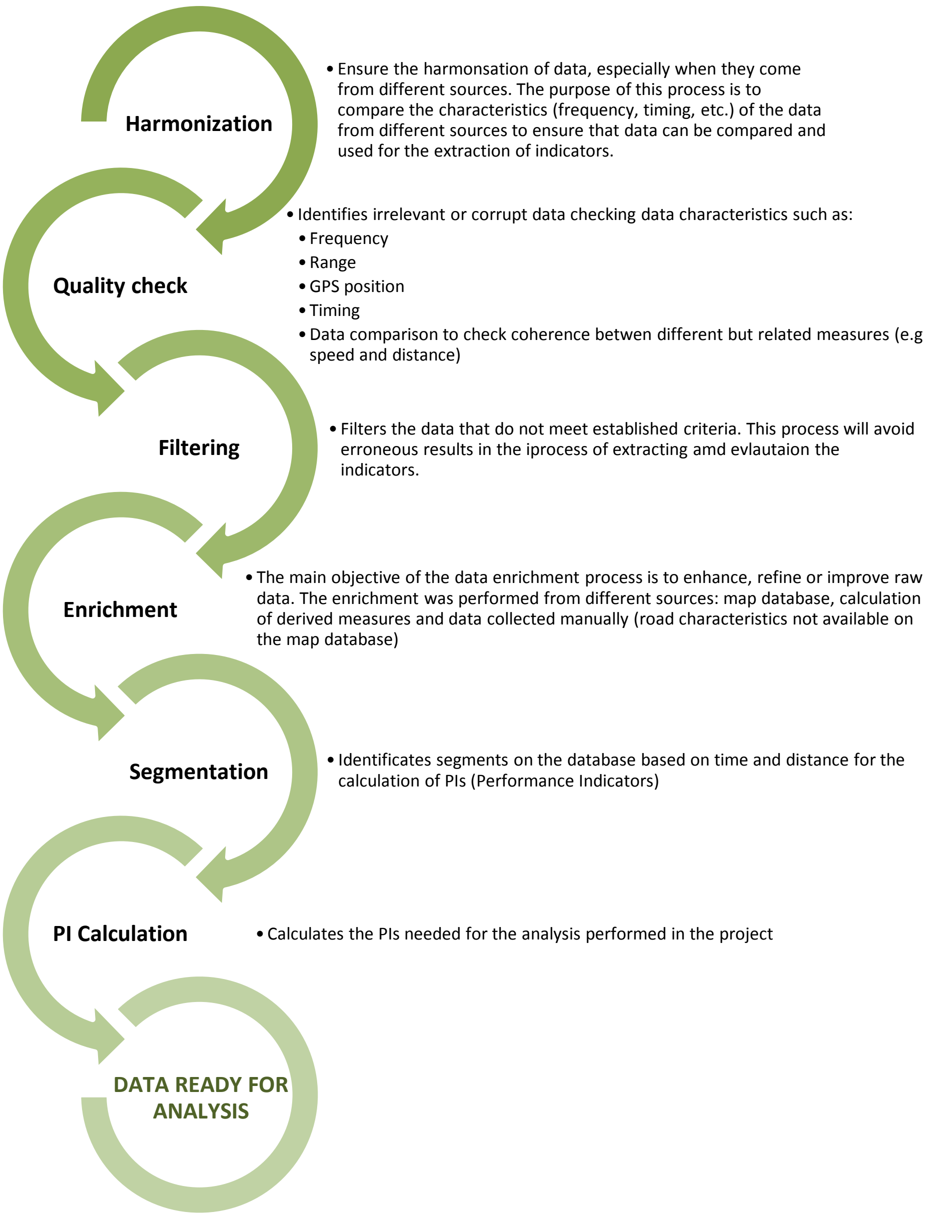


Figure 13: Data processing

3.4 How does the ecoDriver assistance affect the driver?

3.4.1 Introduction

The ecoDriver project tested nine different eco-driving support systems developed within the project under real world driving conditions. The systems differed from each other, but so also did the vehicles used, the data collection systems, and the experimental plan for each trial. These differences made the analyses of the collected data a difficult one. All the required (from a hypothesis perspective) data was not always collected because of lack of availability of sensors. In addition, the same data (signal) could not always be collected with the same accuracy, and the data sets collected were not of equal size. And because of confidentiality not all comparisons could be made. Therefore, an analysis model had to be adopted that could deal with these differences and that could be adapted to different comparisons.

3.4.2 Overview of the systems and experimental designs

In total nine different systems were tested. A summary overview is presented in Table 5. Depending on the performance of the driver or the advice provided for a specific event, the visual information can vary from the screen shots as presented in Table 5.

The systems have been grouped into categories in order not to identify the performance of individual OEM systems and so to avoid benchmarking issues. Five different categories of systems have been identified and also used for further statistical comparisons:

1. **Type A:** All the tested ecoDriver systems are in this category. This allows for global comparisons. For the naturalistic data, this category only contains the TomTom system and the ecoDriver App.
2. **Type B:** This is the embedded systems category including CRF (1), CRF (2), CRF (4), CRF (5), Daimler, BMW, and the Full ecoDriver System (FeDS).
3. **Type C:** This is the Full ecoDriver system (FeDS), individualised since it was built within the ecoDriver project.
4. **Type D:** This is the ecoDriver App, individualised as it was built within the ecoDriver project.
5. **Type E:** All haptic systems belong to this category, i.e. CRF (2) and the Daimler system.

Table 5: The systems tested within the ecoDriver project

System	HMI / Information	Vehicle
CRF (1); Fiat Bravo prototype	Visual / CAN information / no map information	Passenger car
CRF (2); Alfa Romeo Giulietta prototype	Visual and haptic / CAN information / no map information	Passenger car
CRF (3); Alfa Romeo Giulietta prototype	Visual / CAN information / no map information	Passenger car
CRF (4); Lancia Musa prototype	Visual / CAN information / no map information	Passenger car
Daimler	Visual and haptic / CAN information / map information	Truck
BMW	Visual (dashboard and HuD) / CAN information / map information	Passenger car
TomTom	Visual / OBD2 connection / map information	Trucks, vans and buses[4]
ecoDriver App (IFSTTAR / CTAG)	Visual	Passenger cars
Full ecoDriver system (FeDS; CTAG, TNO)	Visual	Passenger cars (CTAG, VTI, IKA, IFSTTAR)

Both “controlled” drives, in which the vehicles were driven along a fixed route, and “naturalistic” drives (ND), in which vehicles were driven in normal daily use, were conducted in the project. Some vehicles were used in only one or the other type of driving. The experimental designs differed between the different test sites, as shown in Table 6. These differences had an impact on the complexity of the statistical analyses performed during the evaluation process. Indeed, due to the large number of test sites and their respective differences (number of test cars, number of routes, number of participants, experiment type), and also technical constraints, it was impossible to harmonise the designs. The statistical methods took these specificities into account as much as possible.

It is important to note that an observer was present in the experimental car for all the controlled drives. The purpose was to collect driving behaviour data such as red light violations or overtakings with the help of a dedicated application. As an observer was present for both driving conditions (without and with the system), the analysis focuses on the differences between these conditions in order to reduce this potential bias. It is impossible to know whether there was an overall effect of observer presence on the results obtained.

[4] The HMI was different on the buses in that an audio alert was used to warn of high fuel consumption, and an OBD2 connection was not used.

Table 6: Overview of the experimental design at the different test sites

Test site	Design	Number participants	Controlled / ND
CRF	Six drives per car; first drive baseline; the final drive of the Alfa Romeo Giulietta was without the haptic pedal; order of cars balanced across participants; participants completed all drives with one car before moving onto the next car	12 (CRF employees)	Controlled
Daimler	Three drives; baseline; visual; visual and haptic; Randomised order; due to the location of the route some drivers experienced the system before the test started. This was also balanced.	24	Controlled
BMW	Three drives; first baseline drive then two experimental drives	10 (BMW employees)	Controlled
TomTom (Trucks)	Baseline, previous TomTom eco-driving solution, system1, system2, system3[5]	10	ND
TomTom (LCVs)	Baseline, previous TomTom eco-driving solution, system1, system2, system35	10	ND
FeDS (VTI)	Baseline (1), **Baseline (2)**, Instruction system (no driving), FeDS (1), FeDS (2), FeDS (3), **FeDS (4)**, FeDS (5), **Baseline (3)**, **Baseline (4)**[6]	12 (10 complete drives)	Controlled
FeDS (IKA)	Baseline, FeDS (1), FeDS (2)	18	Controlled
FeDS (CTAG)	Baseline (1), FeDS, Baseline (2)	30 (CTAG employees)	Controlled
ecoDriver App (CTAG)	Baseline (1), ecoDriver App, Baseline (2)	10 (CTAG employees)	Controlled
ecoDriver App (CTAG)	Baseline (1), ecoDriver App, Baseline (2)	10	ND
ecoDriver App (IFSTTAR)	Baseline (1), ecoDriver App, Baseline (2)	10	ND (plus a controlled drive)
ecoDriver App (IFSTTAR)	Baseline, ecoDriver App	20	Controlled

3.4.3 Hypotheses and analysis methods

An initial list of hypotheses was developed in an early stage of the project as part of the development of the assessment protocol. This list evolved in accordance with technical constraints; some of the hypotheses are addressed in the discussion of how ecoDriver assistance affected the traffic system. The final list of hypotheses is presented in Table 8. Some of these hypotheses are based on commonly used performance indicators, while others are based on an original ecoDriver approach. Four “golden rules” related to the driving behaviour have been identified from the state of the art of eco-driving practices across Europe and tested through hypotheses. The chosen rules used for the ecoDriver project result

[5] The three systems differed in functionalities. All these new functionalities were developed in the ecoDriver project.

[6] FeDS (1) – FeDS (5) are five different drives with the FeDS. Not all drives nor all baselines were used in the analyses. The ones shown in bold were used.

from a trade-off between statistical performance in predicting eco-driving behaviour (Ericsson, 2001; Andrieu and Saint Pierre, 2012), and their link to practical driving rules stated in the literature (see for example the CIECA report, 2007). Although these rules are not an absolute definition of eco-driving, they can be seen as a four-dimensional measure of eco-driving behaviour. These rules are detailed in Table 7.

Table 7: ecoDriver "golden rules" of eco-driving and their respective performance indicators (PIs)

Instruction	Performance Indicator
Rule 1. Shift up as soon as possible: Shift up between 2,000 and 2,500 revolutions per minute.	Average engine speed at the shift into a higher gear
Rule 2. Maintain a steady speed: Use the highest gear possible and drive with low engine RPM.	Index of gear ratio distribution and associated engine speed
Rule 3. Anticipate traffic flow: Look ahead as far as possible and anticipate the surrounding traffic.	Positive Kinetic Energy
Rule 4. Decelerate Smoothly: When you have to slow down or to stop, decelerate smoothly by releasing the accelerator in time, leaving the car in gear.	Percentage of time in engine braking

It is worth noting that the PI-based hypotheses also specify a direction for the expected change according to the state of the art or previous studies. When the expected change is not known, this direction has not been specified in the hypothesis formulation.

Table 8: Summary of the hypotheses studied

Main category	Research Question category	Hypothesis number	Hypothesis
Energy & emissions	ENERGY	1	Using an ecoDriver system will reduce the average fuel consumption Using an ecoDriver system will reduce the average CO_2 emissions
		2	Using an ecoDriver system will reduce the average energy consumption
		3	Using an ecoDriver system will reduce the average NOx emissions
Driver workload and attention	WORKLOAD	4	Using an ecoDriver system will increase driver workload
		5	Workload varies across the different ecoDriver system types
	ATTENTION	6	Using an ecoDriver system (which provides in-trip feedback), drivers are more distracted
		7	In-car feedback from the ecoDriver system causes inappropriate/dangerous visual behaviour, in terms of glances towards the device

Main category	Research Question category	Hypothesis number	Hypothesis
		8	Using an ecoDriver system, the driver will look more at the speedometer/rev counter
Driver behaviour	SPEED	9	Using an ecoDriver system the average velocity when cruising will be lower
		10	Using an ecoDriver system the average free velocity will be lower
	SPEED SITUATIONS		Using an ecoDriver system, speed will change when driving before/at locations where a low speed is recommended by the system, such as:
		11	Location: Intersections
		12	Location: Zebra crossings
		13	Location: Speed bumps
		14	Location: Sharp curves
		15	Location: Crest
		16	Location: Speed limit changes
	THW DISTANCE SITUATIONS	17	Using an ecoDriver system, the time headway distribution to leading vehicle will change
			Using an ecoDriver system, there will be shorter distances to vehicles before/at safety critical locations, such as:
		18	Location: Intersections
		19	Location: Zebra crossings
		20	Location: Speed bumps
		21	Location: Sharp curves
		22	Location: Crest
		23	Location: Speed limit changes
	EVENTS	24	Using an ecoDriver system, there will be more red or amber light violations
		25	Using an ecoDriver system, there will be fewer overtakings
		26	Using an ecoDriver system, there will be less speeding
	4 GOLDEN RULES	27	Using an ecoDriver system, the average rpm when shifting up will be reduced
		28	Using an ecoDriver system, the weighted average engine rpm will be decreased
		29	Using an ecoDriver system, the variability of speed profiles will be decreased
		30	Using an ecoDriver system, the use of the engine brake will be improved
	ACCEL/DECEL	31	Using an ecoDriver system, the acceleration distribution will change

Main category	Research Question category	Hypothesis number	Hypothesis
		32	Using an ecoDriver system, the deceleration distribution will change
		33	Using an ecoDriver system, acceleration after being stationary will be less aggressive
	ACCEL/DECEL SITUATIONS		Using an ecoDriver system, the acceleration distribution will change before/at the following locations:
		34	Location: Intersections
		35	Location: Zebra crossings
		36	Location: Speed bumps
		37	Location: Sharp curves
		38	Location: Crest
		39	Location: Speed limit changes

The overall aim of the ecoDriver analysis was to address almost 40 well-defined hypotheses. Although many statistical analysis methods may exist to answer such questions, from the simplest to far more complex ones, a common scheme has emerged from previous experiences. Indeed, taking full profit from the richness of the data at its finest level (multiple 10 Hz sampled signals) is often a very difficult task. Practitioners rely instead on data reduction methods first, followed by more or less complex linear analysis (Analysis of Variance, Generalised Linear Mixed Models, etc.).

The evaluation approach was largely based on the FESTA Handbook (FOT-Net, 2014). The FESTA approach was applied in the design of the ecoDriver evaluation studies. In ecoDriver Deliverable D41.1 (Kircher et al., 2012), the steps from Research Questions to Hypotheses, to Performance Indicators, Measures and Sensors have been detailed. An overview of the preliminary steps to reduce data and obtain comparable aggregated tables is provided in Figure 13. The chosen aggregation method follows the recommendations of Dozza and Bärgman (2013).

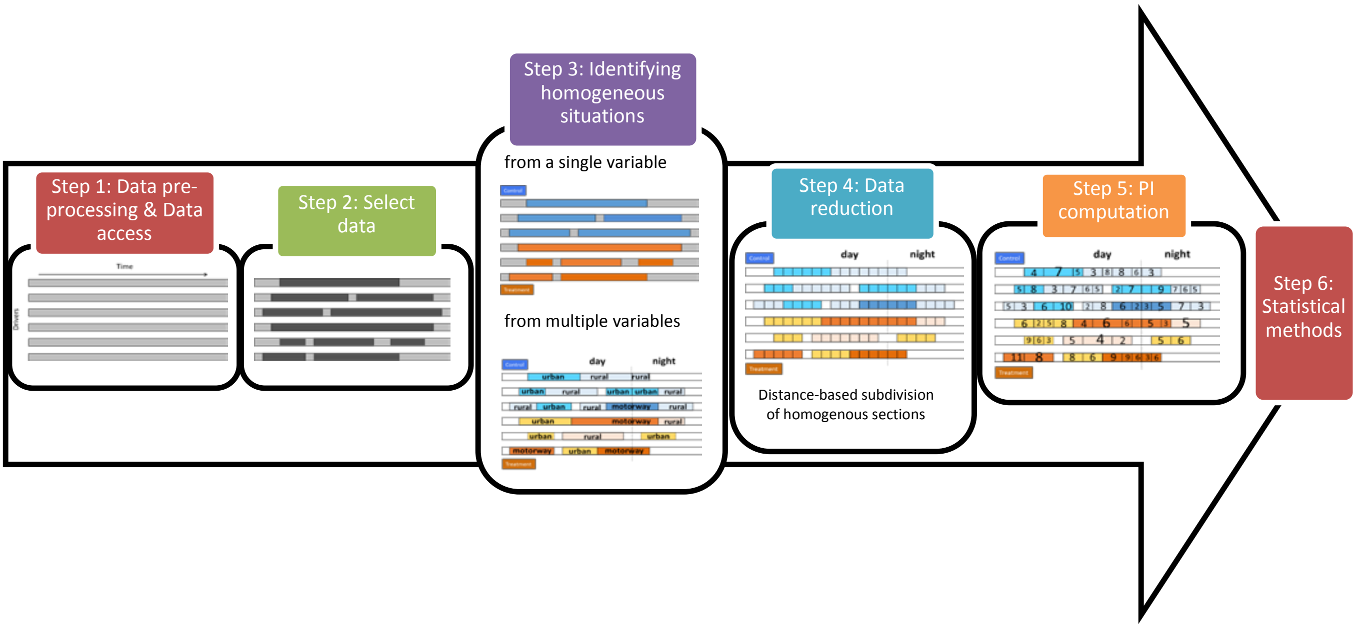


Figure 14: Overview of the data treatment and analysis process for a classical research hypothesis.

This general type of analysis is sometimes called **Aggregation based analysis (ABA).** This is a type of analysis for defining changes between baseline and treatment in terms of how driving performance changes over a range of traffic situations. The driving performance is evaluated through a suitable performance indicator (PI), directly linked to a specific research question. The selection of measures and PI has to reflect ideas on underlying driving behaviour, and in what way a change in the aggregate performance measure is predictive of a change in actual driving behaviour. As the ecoDriver systems should impact driving behaviour on various dimensions, a large number of performance indicators are used to study the impacts on travel efficiency, road safety, fuel consumption, and many other aspects. Usual statistical methods assumes observations are independent of each other, an assumption which does not suit Field Operational Test (FOT) data very well, as it will contain unavoidable driver-specific correlations (i.e. the driving style does not change between trips). To study interacting/confounding factors and to account for these driver specific correlations, more sophisticated statistical models need to be applied. One family of such models is "Generalised Linear Mixed Models" (GLMM). GLMM assumes correlated observations for the same driver, and that there is a random effect associated with each individual driver (i.e. one driver can be associated with higher and another with lower risk of event involvement). This has the additional advantage of allowing controlling for a small population of drivers being involved in a large proportion of safety events, something which indeed may become an issue (Dingus et al., 2006).

Statistical analyses were conducted using R, which is a free software environment for statistical computing and graphics (R Core Team, 2015; Hornik, 2015). A p-level of 0.05 was used to distinguish statistically significant effects. Using open source software allowed for the development of a harmonised common code, with the advantage of reducing errors.

In order to provide an answer to every research question, different data sets have been used. First of all, there are some specific data used for the driver attention studies. These data include questionnaires and eye tracker data that may not be described numerically.

A total of six different systems, and several additional sub-versions, have been evaluated within the ecoDriver project. For industrial confidentiality reasons, it is only possible to treat the full ecoDriver system (FeDs) and the ecoDriver App as individual systems; the others were merged into three different categories (All systems, Embedded systems, Haptic systems), each one of them being associated with a corresponding baseline. These constraints lead to the statistical comparisons depicted in Figure 14.

Energy related and driver behaviour hypotheses share the same analysis framework based on studying specifically a set of comparisons, from the more global to the more specific. Figure 14 presents the main comparisons, with the corresponding name of the dataset. Each data set type is different because it is linked to different VMCs and systems. The Embedded systems (Type B) are the OEM systems and the FeDS, i.e. systems that use detailed vehicle data from the CAN bus or OBD2. In contrast, the ecoDriver App (type D) does not use such detailed vehicle data. Further, it is worth noting that only the first global comparison can be assessed using naturalistic driving data.

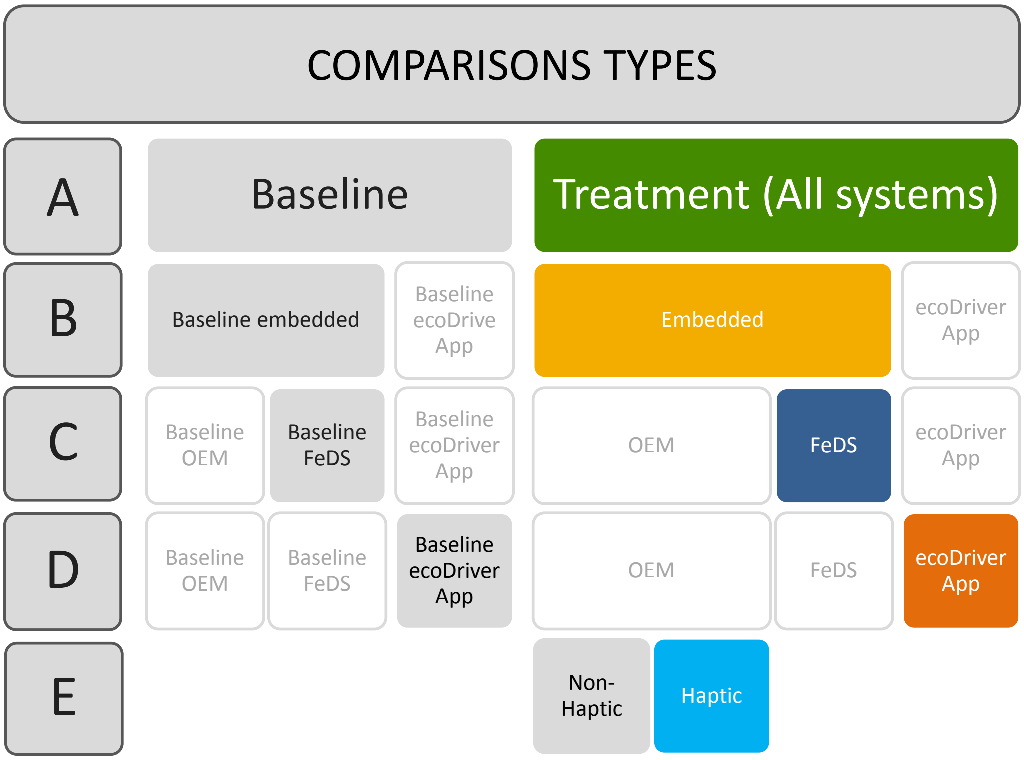


Figure 15: Overview of comparison types A through E

For comparison types A through D, the analysis consisted of *baseline versus treatment*, i.e. without versus with the given system(s). For comparison Type E, the comparison was *with versus without haptic feedback*, i.e. a system that included haptic feedback versus the same system without haptic feedback. (but both always have visual feedback). Each hypothesis presented in Table 8 is therefore analysed for each of the five comparisons (Type A to E) using the controlled data. Additionally, the Type A comparison has been studied using only naturalistic data. The naturalistic data set does not contain any data from the TomTom trial due to strong indications that the trial results were contaminated by external factors, in particular differing levels of traffic congestion between the baseline and treatment periods. The various comparison types lead to a total of six different comparisons for each research question.

3.4.4 Overview of results

After a careful statistical analysis, numerous results from paired comparisons have been obtained for almost 40 different research questions. They are displayed in a summarised form in Table 9

Effect sizes in percentages (differences in % from relevant baseline)									
Hyp. Number & cat.	**PI abbreviated**	**Road type**	**Treatment (all systems) Type A**	**Embedded Type B**	**FeDS Type C**	**App Type D**	**Haptic Type E**	**Naturalistic (App) Type A**
1 Energy	% of reduction for fuel consumption & CO2	Urban	2.58	2.98	-1.28 (N.S.)	1.54 (N.S.)	3.12 (N.S.)	-1.57 (N.S.)
		Rural	5.76	6.03	2.66	3.15 (N.S.)	2.83 (N.S.)	-2.49 (N.S.)
		Motorway	2.21 (N.S.)	2.24 (N.S.)	1.53 (N.S.)	-	-	0.3 (N.S.)
		All road types	4.2	4.38	1.46	2.54	2.73 (N.S.)	-0.8 (N.S.)
2 Energy	% of energy consumption reduction	Urban	-	-	-9.24 (N.S.)	-	-	-
		Rural	-	-	3.16 (N.S.)	-	-	-
		Motorway	-	-	6.72 (N.S.)	-	-	-
		All road types	-	-	-0.38 (N.S.)	-	-	-
3 Energy	% of NoX reduction compared to resp. baseline	Urban	2.61	3.27	1.64 (N.S.)	-0.28 (N.S.)	1.77 (N.S.)	-1.07 (N.S.)
		Rural	5.11	5.65	4.09	2.35 (N.S.)	0.1 (N.S.)	-0.9 (N.S.)
		Motorway	3.29	3.34	2.79 (N.S.)	-	-	3.44
		All road types	4.04	4.49	3.18	1.34 (N.S.)	0.67 (N.S.)	0.97 (N.S.)
9 Speed	Average speed when cruising	Urban	-2.79	3.30	4.76	-8.86 (N.S.)	3.63	3.28
		Rural	4.04	1.82	1.71 (N.S.)	2.17 (N.S.)	-0.95 (N.S.)	0.03 (N.S.)
		Motorway	3.42	3.32	3.50	-	-	1.25
		All road types	2.39	2.53	2.95	-	0.74 (N.S.)	1.24
10 Speed	Average speed when freely driving	Urban	3.07 (N.S.)	10.61	9.83	0.45 (N.S.)	-11.87 (N.S.)	-
		Rural	3.55	0.37 (N.S.)	0.37 (N.S.)	1.31 (N.S.)	-0.05 (N.S.)	-
		Motorway	0.57 (N.S.)	0.67 (N.S.)	0.62 (N.S.)	-	-	-
		All road types	2.97	4.06	2.78	1.18 (N.S.)	4.84 (N.S.)	-
11 Speed Situations	avg_speed_distance_based before intersections	Urban	-3.14	-0.13 (N.S.)	2.76	-1.4 (N.S.)	1.1 (N.S.)	-
		Rural	5.60	3.47	1.82	1.78	1.22 (N.S.)	-
		Motorway	5.08	5.01	2.57	-	-	-
		All road types	1.32	1.66	1.58	-0.61 (N.S.)	1.00	-
12 Speed Situations	avg_speed_distance_based before zebra crossings	Urban	-0.99 (N.S.)	2.33	4.18	0.49 (N.S.)	0.07 (N.S.)	-
		Rural	13.13	2.43 (N.S.)	3.47 (N.S.)	3.18	-1.83 (N.S.)	-
		Motorway	7.6 (N.S.)	7.58 (N.S.)	7.19 (N.S.)	-	-	-
		All road types	1.29	2.22	3.53	0.59 (N.S.)	-0.08 (N.S.)	-
		Urban	1.1 (N.S.)	2.26 (N.S.)	1.32 (N.S.)	0.6 (N.S.)	-6.61 (N.S.)	-

13 Speed Situations	avg_speed_distance_based before speedbumps	Rural	0.99 (N.S.)	1.65 (N.S.)	1.88 (N.S.)	-0.12 (N.S.)	-	-
		Motorway	-	-	-	-	-	-
		All road types	0.77 (N.S.)	1.46 (N.S.)	0.37 (N.S.)	-0.12 (N.S.)	-6.61 (N.S.)	-

Effect sizes in percentages (differences in % from relevant baseline)								
Hyp. Number & cat.	**PI abbreviated**	**Road type**	**Treatment (all systems) Type A**	**Embedded Type B**	**FeDS Type C**	**App Type D**	**Haptic Type E**	**Naturalistic (App) Type A**
14 Speed Situations	avg_speed_distance_based before sharp curves	Urban	-2.38 (N.S.)	1.35 (N.S.)	1.85 (N.S.)	3.26 (N.S.)	4.96	-
		Rural	3.72	2.45	3.40	1.35 (N.S.)	-1.46 (N.S.)	-
		Motorway	0.44 (N.S.)	0.22 (N.S.)	5.1 (N.S.)	-	-	-
		All road types	1.33	1.83	2.24	-0.79 (N.S.)	1.18 (N.S.)	-
15 Speed Situations	avg_speed_distance_based at crests	Urban	0.87 (N.S.)	0.94 (N.S.)	0.69 (N.S.)	2.25 (N.S.)	2.5 (N.S.)	-
		Rural	1.25 (N.S.)	1.08 (N.S.)	0.34 (N.S.)	2.16	1.18 (N.S.)	-
		Motorway	-2.66 (N.S.)	-2.65 (N.S.)	-2.62 (N.S.)	-	-	-
		All road types	1.68	1.59 (N.S.)	1.29 (N.S.)	2.21	1.06 (N.S.)	-
16 Speed Situations	avg_speed_distance_based before speed limit changes	Urban	1.41 (N.S.)	2.54 (N.S.)	4.2 (N.S.)	3.08 (N.S.)	1.14 (N.S.)	-
		Rural	2.30	2.36	2.35 (N.S.)	0.74 (N.S.)	-2.67 (N.S.)	-
		Motorway	6.42	6.31	4.24	-	-	-
		All road types	2.56	2.98	3.06	1.45 (N.S.)	-1.23 (N.S.)	-
17 THW Situations	Average time headway	Urban	6.50	11.15	12.23	3.97 (N.S.)	-	-
		Rural	5.86	5.65 (N.S.)	4.71 (N.S.)	-1.88 (N.S.)	-	-
		Motorway	8.56	9.17	12.36	-	-	-
		All road types	6.29	9.06	10.24	-0.33 (N.S.)	4.45 (N.S.)	-
18 THW Situations	Average time headway before intersections	Urban	8.10	12.93	13.87	3.67 (N.S.)	-	-
		Rural	2.6 (N.S.)	4.58	5.45 (N.S.)	-7.63 (N.S.)	-	-
		Motorway	-	-	-	-	-	-
		All road types	5.63	9.57	10.36	-1 (N.S.)	15.23	-
19 THW Situations	Average time headway before zebra crossings	Urban	-1.42 (N.S.)	2.87 (N.S.)	1.95 (N.S.)	-2.11 (N.S.)	-	-
		Rural	1.67 (N.S.)	-3.1 (N.S.)	-3.54 (N.S.)	4.45 (N.S.)	-	-
		Motorway	-	-	-	-	-	-
		All road types	-1.13 (N.S.)	1.42 (N.S.)	0.32 (N.S.)	-1.74 (N.S.)	11.64 (N.S.)	-
20 THW Situations	Average time headway before speed bumps	Urban	6.77 (N.S.)	8.12 (N.S.)	8.12 (N.S.)	6.47 (N.S.)	-	-
		Rural	0.32 (N.S.)	-6.8 (N.S.)	-6.8 (N.S.)	8.06 (N.S.)	-	-
		Motorway	-	-	-	-	-	-
		All road types	4.49 (N.S.)	0.69 (N.S.)	0.69 (N.S.)	6.33 (N.S.)	-	-
21 THW Situations	Average time headway before sharp curves	Urban	4.62 (N.S.)	16.54	22.27	0.56 (N.S.)	-	-
		Rural	7.87 (N.S.)	3.73 (N.S.)	2.73 (N.S.)	8.37 (N.S.)	-	-

		Motorway	-	-	-	-	-	-
		All road types	4.73 (N.S.)	8.36	8.68	1.32 (N.S.)	-	-

Effect sizes in percentages (differences in % from relevant baseline)								
Hyp. Number & cat.	PI abbreviated	Road type	Treatment (all systems) Type A	Embedded Type B	FeDS Type C	App Type D	Haptic Type E	Naturalistic (App) Type A
23 THW Situations	Average time headway before speed limit changes	Urban	7.19	13.95	16.80	5.59 (N.S.)	-	-
		Rural	3.79 (N.S.)	3.42 (N.S.)	3.39 (N.S.)	-0.36 (N.S.)	-	-
		Motorway	11.36 (N.S.)	12.24 (N.S.)	17.8 (N.S.)	-	-	-
		All road types	5.43	8.22	9.70	1.33 (N.S.)	-	-
27 Golden rules	Average rpm when shifting gear up	Urban	-0.73 (N.S.)	5.63	6.68	7.34	3.76 (N.S.)	3.85
		Rural	11.44	9.97	12.23	7.43	1.35 (N.S.)	8.29
		Motorway	3.19	3.42	3.32	-	-	2.19
		All road types	7.09	7.14	7.90	8.03	1.92 (N.S.)	2.97
28 Golden rules	weighted average engine rpm	Urban	2.48	9.12	9.39	7.70	-0.99 (N.S.)	7.13
		Rural	14.43	13.95	14.20	6.00	0.89 (N.S.)	9.12
		Motorway	4.15	4.41	3.72	-	-	2.24 (N.S.)
		All road types	9.64	10.24	9.46	7.03	0.42 (N.S.)	5.00
29 Golden rules	Positive kinetic energy	Urban	6.25	3.23	3.17	1.45 (N.S.)	0 (N.S.)	1.56 (N.S.)
		Rural	1.72	5.00	3.51	0 (N.S.)	1.54 (N.S.)	0 (N.S.)
		Motorway	0 (N.S.)	0 (N.S.)	0 (N.S.)	-	-	0 (N.S.)
		All road types	3.39	3.39	1.79	0 (N.S.)	1.52 (N.S.)	1.69
30 Golden rules	Percentage of driving time with engine brake	Urban	-2.89 (N.S.)	1 (N.S.)	2.15 (N.S.)	1.96 (N.S.)	-2.86 (N.S.)	-0.71 (N.S.)
		Rural	5.13	1.48 (N.S.)	5.11	6.38	-5.61 (N.S.)	3.73 (N.S.)
		Motorway	1.89 (N.S.)	2.24 (N.S.)	2.15 (N.S.)	-	-	-4.73
		All road types	1.83	1.17 (N.S.)	3.29	4.90	-5.11	-0.54 (N.S.)
31 Accel Decel	95th percentile positive acceleration	Urban	13.12	8.54	5.17	2.11 (N.S.)	-4.38 (N.S.)	4.77
		Rural	4.43	13.21	8.42	1.61 (N.S.)	3.59 (N.S.)	3.06 (N.S.)
		Motorway	-1.2 (N.S.)	0 (N.S.)	5.8 (N.S.)	-	-	7.44 (N.S.)
		All road types	8.10	9.81	6.57	1.12 (N.S.)	-0.09 (N.S.)	4.57
32 Accel Decel	5th percentile negative acceleration	Urban	11.34	5.11	6.45	0.65 (N.S.)	0 (N.S.)	3.88
		Rural	3.64	14.65	7.14	-1.54 (N.S.)	4.65 (N.S.)	3.28 (N.S.)
		Motorway	0 (N.S.)	0 (N.S.)	3.7 (N.S.)	-	-	7.38
		All road types	7.46	9.02	5.80	-1.05 (N.S.)	1.92 (N.S.)	4.31
33 Accel Decel	maximum acceleration after stationnary	Urban	2.22	2.94	0.7 (N.S.)	1.77	-4.21 (N.S.)	-
		Rural	-	-	-	-	-	-

		Motorway	-	-	-	-	-	-
		All road types	-	-	-	-	-	-

Effect sizes in percentages (differences in % from relevant baseline)								
Hyp. Number & cat.	**PI abbreviated**	**Road type**	**Treatment (all systems) Type A**	**Embedded Type B**	**FeDS Type C**	**App Type D**	**Haptic Type E**	**Naturalistic (App) Type A**
34 Accel Decel Situation	95th percentile of the negative acceleration before intersections	Urban	4.95	4.74	3.94	-0.09 (N.S.)	3.50	-
		Rural	-0.94	4.38	3.64	-1.42 (N.S.)	1.01 (N.S.)	-
		Motorway	-	-	-	-	-	-
		All road types	3.12	4.59	3.84	-	-	-
35 Accel Decel Situation	95th percentile of the negative acceleration before zebra crossings	Urban	2.39	2.61 (N.S.)	4.19 (N.S.)	0.76 (N.S.)	5.25 (N.S.)	-
		Rural	-11.03	6.51 (N.S.)	15.75	-7.55 (N.S.)	-2.84 (N.S.)	-
		Motorway	-	-	-	-	-	-
		All road types	1.53	3.07	5.72	0.56 (N.S.)	4.30	-
36 Accel Decel Situation	95th percentile of the negative acceleration before speed bumps	Urban	6.43	10.95	16.96	4.49	2.06 (N.S.)	-
		Rural	12.37	12.82	12.89	11.98	-	-
		Motorway	-	-	-	-	-	-
		All road types	7.02	11.06	15.40	4.91	-	-
37 Accel Decel Situation	95th percentile of the negative acceleration before sharp curves	Urban	3.44	4.09	1.96 (N.S.)	-0.7 (N.S.)	8.24	-
		Rural	4.25	5.41	4.13	0.78 (N.S.)	1.27 (N.S.)	-
		Motorway	-	-	-	-	-	-
		All road types	3.88	4.80	3.28	0.18 (N.S.)	4.51	-
38 Accel Decel Situation	95th percentile of the negative acceleration at crests	Urban	0.65 (N.S.)	0.66 (N.S.)	0.59 (N.S.)	-	-	-
		Rural	4.18 (N.S.)	5.62	5.48 (N.S.)	-1.57 (N.S.)	-3.75 (N.S.)	-
		Motorway	-	-	-	-	-	-
		All road types	3.44	4.31	3.89	-	-	-
39 Accel Decel Situation	95th percentile of the negative acceleration before speed limit changes	Urban	1.42 (N.S.)	2.57 (N.S.)	2.87 (N.S.)	-2.01 (N.S.)	8.24	-
		Rural	4.11	4.94	1.69 (N.S.)	0.21 (N.S.)	1.27 (N.S.)	-
		Motorway	-	-	-	-	-	-
		All road types	2.96	3.83	2.09 (N.S.)	-0.4 (N.S.)	4.51	-

. The results reported below are *statistically significant* differences. When no statistical difference was found, it does not mean that there is in reality no effect. It can also mean that the power of the test is not strong enough to show reliably a statistical difference.

In Table 9, the significant results are colour-coded. Green indicates a positive effect when using the ecoDriver systems, while red indicates a negative effect. The darker the green or red, the stronger is the effect. No colour indicates a non-significant difference. For example, looking at hypothesis 10 about changes in the average free speed, the green cells indicate a significant decrease of the average free speed, and therefore a safer and more eco-friendly driving behaviour.

Note that for the naturalistic trials, some results are missing simply because we do not have precise map information, and so we were unable to extract situations (intersections, traffic lights, speed bump etc.). Also, there was no radar on the vehicles in the naturalistic trials, so that no measure of time headway was possible.

Table 9: Summary of results for all the hypotheses tested using a PI based approach. Significant cells are coloured from red (negative impact) to green (positive impact).

Effect sizes in percentages (differences in % from relevant baseline)								
Hyp. Number & cat.	**PI abbreviated**	**Road type**	**Treatment (all systems) Type A**	**Embedded Type B**	**FeDS Type C**	**App Type D**	**Haptic Type E**	**Naturalistic (App) Type A**
1 Energy	% of reduction for fuel consumption & CO2	Urban	2.58	2.98	-1.28 (N.S.)	1.54 (N.S.)	3.12 (N.S.)	-1.57 (N.S.)
		Rural	5.76	6.03	2.66	3.15 (N.S.)	2.83 (N.S.)	-2.49 (N.S.)
		Motorway	2.21 (N.S.)	2.24 (N.S.)	1.53 (N.S.)	-	-	0.3 (N.S.)
		All road types	4.2	4.38	1.46	2.54	2.73 (N.S.)	-0.8 (N.S.)
2 Energy	% of energy consumption reduction[7]	Urban	-	-	-9.24 (N.S.)	-	-	-
		Rural	-	-	3.16 (N.S.)	-	-	-
		Motorway	-	-	6.72 (N.S.)	-	-	-
		All road types	-	-	-0.38 (N.S.)	-	-	-
3 Energy	% of NoX reduction compared to resp. baseline	Urban	2.61	3.27	1.64 (N.S.)	-0.28 (N.S.)	1.77 (N.S.)	-1.07 (N.S.)
		Rural	5.11	5.65	4.09	2.35 (N.S.)	0.1 (N.S.)	-0.9 (N.S.)
		Motorway	3.29	3.34	2.79 (N.S.)	-	-	3.44
		All road types	4.04	4.49	3.18	1.34 (N.S.)	0.67 (N.S.)	0.97 (N.S.)
9 Speed	Average speed when cruising	Urban	-2.79	3.30	4.76	-8.86 (N.S.)	3.63	3.28
		Rural	4.04	1.82	1.71 (N.S.)	2.17 (N.S.)	-0.95 (N.S.)	0.03 (N.S.)
		Motorway	3.42	3.32	3.50	-	-	1.25
		All road types	2.39	2.53	2.95	-	0.74 (N.S.)	1.24
10 Speed	Average speed when freely driving	Urban	3.07 (N.S.)	10.61	9.83	0.45 (N.S.)	-11.87 (N.S.)	-
		Rural	3.55	0.37 (N.S.)	0.37 (N.S.)	1.31 (N.S.)	-0.05 (N.S.)	-
		Motorway	0.57 (N.S.)	0.67 (N.S.)	0.62 (N.S.)	-	-	-
		All road types	2.97	4.06	2.78	1.18 (N.S.)	4.84 (N.S.)	-
11 Speed Situations	avg_speed_distance_based before intersections	Urban	-3.14	-0.13 (N.S.)	2.76	-1.4 (N.S.)	1.1 (N.S.)	-
		Rural	5.60	3.47	1.82	1.78	1.22 (N.S.)	-
		Motorway	5.08	5.01	2.57	-	-	-
		All road types	1.32	1.66	1.58	-0.61 (N.S.)	1.00	-
12 Speed Situations	avg_speed_distance_based before zebra crossings	Urban	-0.99 (N.S.)	2.33	4.18	0.49 (N.S.)	0.07 (N.S.)	-
		Rural	13.13	2.43 (N.S.)	3.47 (N.S.)	3.18	-1.83 (N.S.)	-
		Motorway	7.6 (N.S.)	7.58 (N.S.)	7.19 (N.S.)	-	-	-
		All road types	1.29	2.22	3.53	0.59 (N.S.)	-0.08 (N.S.)	-
13 Speed Situations	avg_speed_distance_based before speedbumps	Urban	1.1 (N.S.)	2.26 (N.S.)	1.32 (N.S.)	0.6 (N.S.)	-6.61 (N.S.)	-
		Rural	0.99 (N.S.)	1.65 (N.S.)	1.88 (N.S.)	-0.12 (N.S.)	-	-
		Motorway	-	-	-	-	-	-
		All road types	0.77 (N.S.)	1.46 (N.S.)	0.37 (N.S.)	-0.12 (N.S.)	-6.61 (N.S.)	-

[7] This hypothesis relates to electric vehicle energy use only, as collected in one of the controlled trials of the FeDS system.

Effect sizes in percentages (differences in % from relevant baseline)								
Hyp. Number & cat.	**PI abbreviated**	**Road type**	**Treatment (all systems) Type A**	**Embedded Type B**	**FeDS Type C**	**App Type D**	**Haptic Type E**	**Naturalistic (App) Type A**
14 Speed Situations	avg_speed_distance_based before sharp curves	Urban	-2.38 (N.S.)	1.35 (N.S.)	1.85 (N.S.)	3.26 (N.S.)	4.96	-
		Rural	3.72	2.45	3.40	1.35 (N.S.)	-1.46 (N.S.)	-
		Motorway	0.44 (N.S.)	0.22 (N.S.)	5.1 (N.S.)	-	-	-
		All road types	1.33	1.83	2.24	-0.79 (N.S.)	1.18 (N.S.)	-
15 Speed Situations	avg_speed_distance_based at crests	Urban	0.87 (N.S.)	0.94 (N.S.)	0.69 (N.S.)	2.25 (N.S.)	2.5 (N.S.)	-
		Rural	1.25 (N.S.)	1.08 (N.S.)	0.34 (N.S.)	2.16	1.18 (N.S.)	-
		Motorway	-2.66 (N.S.)	-2.65 (N.S.)	-2.62 (N.S.)	-	-	-
		All road types	1.68	1.59 (N.S.)	1.29 (N.S.)	2.21	1.06 (N.S.)	-
16 Speed Situations	avg_speed_distance_based before speed limit changes	Urban	1.41 (N.S.)	2.54 (N.S.)	4.2 (N.S.)	3.08 (N.S.)	1.14 (N.S.)	-
		Rural	2.30	2.36	2.35 (N.S.)	0.74 (N.S.)	-2.67 (N.S.)	-
		Motorway	6.42	6.31	4.24	-	-	-
		All road types	2.56	2.98	3.06	1.45 (N.S.)	-1.23 (N.S.)	-
17 THW Situations	Average time headway	Urban	6.50	11.15	12.23	3.97 (N.S.)	-	-
		Rural	5.86	5.65 (N.S.)	4.71 (N.S.)	-1.88 (N.S.)	-	-
		Motorway	8.56	9.17	12.36	-	-	-
		All road types	6.29	9.06	10.24	-0.33 (N.S.)	4.45 (N.S.)	-
18 THW Situations	Average time headway before intersections	Urban	8.10	12.93	13.87	3.67 (N.S.)	-	-
		Rural	2.6 (N.S.)	4.58	5.45 (N.S.)	-7.63 (N.S.)	-	-
		Motorway	-	-	-	-	-	-
		All road types	5.63	9.57	10.36	-1 (N.S.)	15.23	-
19 THW Situations	Average time headway before zebra crossings	Urban	-1.42 (N.S.)	2.87 (N.S.)	1.95 (N.S.)	-2.11 (N.S.)	-	-
		Rural	1.67 (N.S.)	-3.1 (N.S.)	-3.54 (N.S.)	4.45 (N.S.)	-	-
		Motorway	-	-	-	-	-	-
		All road types	-1.13 (N.S.)	1.42 (N.S.)	0.32 (N.S.)	-1.74 (N.S.)	11.64 (N.S.)	-
20 THW Situations	Average time headway before speed bumps	Urban	6.77 (N.S.)	8.12 (N.S.)	8.12 (N.S.)	6.47 (N.S.)	-	-
		Rural	0.32 (N.S.)	-6.8 (N.S.)	-6.8 (N.S.)	8.06 (N.S.)	-	-
		Motorway	-	-	-	-	-	-
		All road types	4.49 (N.S.)	0.69 (N.S.)	0.69 (N.S.)	6.33 (N.S.)	-	-
21 THW Situations	Average time headway before sharp curves	Urban	4.62 (N.S.)	16.54	22.27	0.56 (N.S.)	-	-
		Rural	7.87 (N.S.)	3.73 (N.S.)	2.73 (N.S.)	8.37 (N.S.)	-	-
		Motorway	-	-	-	-	-	-
		All road types	4.73 (N.S.)	8.36	8.68	1.32 (N.S.)	-	-

Effect sizes in percentages (differences in % from relevant baseline)								
Hyp. Number & cat.	**PI abbreviated**	**Road type**	**Treatment (all systems) Type A**	**Embedded Type B**	**FeDS Type C**	**App Type D**	**Haptic Type E**	**Naturalistic (App) Type A**
23 THW Situations	Average time headway before speed limit changes	Urban	7.19	13.95	16.80	5.59 (N.S.)	-	-
		Rural	3.79 (N.S.)	3.42 (N.S.)	3.39 (N.S.)	-0.36 (N.S.)	-	-
		Motorway	11.36 (N.S.)	12.24 (N.S.)	17.8 (N.S.)	-	-	-
		All road types	5.43	8.22	9.70	1.33 (N.S.)	-	-
27 Golden rules	Average rpm when shifting gear up	Urban	-0.73 (N.S.)	5.63	6.68	7.34	3.76 (N.S.)	3.85
		Rural	11.44	9.97	12.23	7.43	1.35 (N.S.)	8.29
		Motorway	3.19	3.42	3.32	-	-	2.19
		All road types	7.09	7.14	7.90	8.03	1.92 (N.S.)	2.97
28 Golden rules	weighted average engine rpm	Urban	2.48	9.12	9.39	7.70	-0.99 (N.S.)	7.13
		Rural	14.43	13.95	14.20	6.00	0.89 (N.S.)	9.12
		Motorway	4.15	4.41	3.72	-	-	2.24 (N.S.)
		All road types	9.64	10.24	9.46	7.03	0.42 (N.S.)	5.00
29 Golden rules	Positive kinetic energy	Urban	6.25	3.23	3.17	1.45 (N.S.)	0 (N.S.)	1.56 (N.S.)
		Rural	1.72	5.00	3.51	0 (N.S.)	1.54 (N.S.)	0 (N.S.)
		Motorway	0 (N.S.)	0 (N.S.)	0 (N.S.)	-	-	0 (N.S.)
		All road types	3.39	3.39	1.79	0 (N.S.)	1.52 (N.S.)	1.69
30 Golden rules	Percentage of driving time with engine brake	Urban	-2.89 (N.S.)	1 (N.S.)	2.15 (N.S.)	1.96 (N.S.)	-2.86 (N.S.)	-0.71 (N.S.)
		Rural	5.13	1.48 (N.S.)	5.11	6.38	-5.61 (N.S.)	3.73 (N.S.)
		Motorway	1.89 (N.S.)	2.24 (N.S.)	2.15 (N.S.)	-	-	-4.73
		All road types	1.83	1.17 (N.S.)	3.29	4.90	-5.11	-0.54 (N.S.)
31 Accel Decel	95th percentile positive acceleration	Urban	13.12	8.54	5.17	2.11 (N.S.)	-4.38 (N.S.)	4.77
		Rural	4.43	13.21	8.42	1.61 (N.S.)	3.59 (N.S.)	3.06 (N.S.)
		Motorway	-1.2 (N.S.)	0 (N.S.)	5.8 (N.S.)	-	-	7.44 (N.S.)
		All road types	8.10	9.81	6.57	1.12 (N.S.)	-0.09 (N.S.)	4.57
32 Accel Decel	5th percentile negative acceleration	Urban	11.34	5.11	6.45	0.65 (N.S.)	0 (N.S.)	3.88
		Rural	3.64	14.65	7.14	-1.54 (N.S.)	4.65 (N.S.)	3.28 (N.S.)
		Motorway	0 (N.S.)	0 (N.S.)	3.7 (N.S.)	-	-	7.38
		All road types	7.46	9.02	5.80	-1.05 (N.S.)	1.92 (N.S.)	4.31
33 Accel Decel	maximum acceleration after stationnary	Urban	2.22	2.94	0.7 (N.S.)	1.77	-4.21 (N.S.)	-
		Rural	-	-	-	-	-	-
		Motorway	-	-	-	-	-	-
		All road types	-	-	-	-	-	-

Effect sizes in percentages (differences in % from relevant baseline)								
Hyp. Number & cat.	**PI abbreviated**	**Road type**	**Treatment (all systems) Type A**	**Embedded Type B**	**FeDS Type C**	**App Type D**	**Haptic Type E**	**Naturalistic (App) Type A**
34 Accel Decel Situation	95th percentile of the negative acceleration before intersections	Urban	4.95	4.74	3.94	-0.09 (N.S.)	3.50	-
		Rural	-0.94	4.38	3.64	-1.42 (N.S.)	1.01 (N.S.)	-
		Motorway	-	-	-	-	-	-
		All road types	3.12	4.59	3.84	-	-	-
35 Accel Decel Situation	95th percentile of the negative acceleration before zebra crossings	Urban	2.39	2.61 (N.S.)	4.19 (N.S.)	0.76 (N.S.)	5.25 (N.S.)	-
		Rural	-11.03	6.51 (N.S.)	15.75	-7.55 (N.S.)	-2.84 (N.S.)	-
		Motorway	-	-	-	-	-	-
		All road types	1.53	3.07	5.72	0.56 (N.S.)	4.30	-
36 Accel Decel Situation	95th percentile of the negative acceleration before speed bumps	Urban	6.43	10.95	16.96	4.49	2.06 (N.S.)	-
		Rural	12.37	12.82	12.89	11.98	-	-
		Motorway	-	-	-	-	-	-
		All road types	7.02	11.06	15.40	4.91	-	-
37 Accel Decel Situation	95th percentile of the negative acceleration before sharp curves	Urban	3.44	4.09	1.96 (N.S.)	-0.7 (N.S.)	8.24	-
		Rural	4.25	5.41	4.13	0.78 (N.S.)	1.27 (N.S.)	-
		Motorway	-	-	-	-	-	-
		All road types	3.88	4.80	3.28	0.18 (N.S.)	4.51	-
38 Accel Decel Situation	95th percentile of the negative acceleration at crests	Urban	0.65 (N.S.)	0.66 (N.S.)	0.59 (N.S.)	-	-	-
		Rural	4.18 (N.S.)	5.62	5.48 (N.S.)	-1.57 (N.S.)	-3.75 (N.S.)	-
		Motorway	-	-	-	-	-	-
		All road types	3.44	4.31	3.89	-	-	-
39 Accel Decel Situation	95th percentile of the negative acceleration before speed limit changes	Urban	1.42 (N.S.)	2.57 (N.S.)	2.87 (N.S.)	-2.01 (N.S.)	8.24	-
		Rural	4.11	4.94	1.69 (N.S.)	0.21 (N.S.)	1.27 (N.S.)	-
		Motorway	-	-	-	-	-	-
		All road types	2.96	3.83	2.09 (N.S.)	-0.4 (N.S.)	4.51	-

The main findings are presented below; for each research question category (energy and emissions, driver workload and attention, etc.), three sets of results are presented. The first reports the combined effects of all the ecoDriver systems, the second provides a comparison across road types and the third details the comparison of different system categories (embedded versus nomadic for example). The exception to this are the results for workload and attention, which are presented more globally due to the data collection methodology. In addition the scarcity of event-based data (overtaking and violations) meant that these were not subjected to this pattern of analysis.

3.4.5 Main findings — energy and emissions

ENERGY

- Using an ecoDriver system will reduce the average fuel consumption & CO2 emission (per 100km).
- Using an ecoDriver system will reduce the average NOx emissions (per 100km).
- Using an ecoDriver system will reduce the average energy consumption (per km or 100km).

i. **Across all systems,** reductions in fuel consumption and CO_2 have an average value of 4.2%. Considering different road types they ranged from 2.2% (non-significant reduction of energy on motorways where the sample is smaller) to 5.8% (significant reduction of energy on rural roads). Reductions in NOx emissions have a similar average value of 4% and are significant on all road types ranging from 2.6% (urban) to 5.1% (rural). In the naturalistic data, a significant reduction of NOx emissions of 3.4% on motorways is found.

ii. **Comparing the results across road types**, the ecoDriver systems reduced fuel consumption and CO_2 emissions by up to 5.76% (urban), with more impact on rural roads (5.8%). The same tendency for a bigger impact on rural roads is present for NOx reduction, with a saving of up to 5.1% on rural roads.

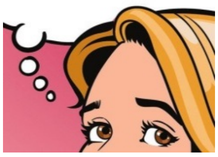
iii. **When grouping the systems by categories,** the ecoDriver embedded systems (which use detailed vehicle data from the CAN bus or OBD2) performed better than the App, with fuel savings of up to 6% and of NOx up to 5.7% on rural roads. Individually, the FeDS had a significant impact on both fuel/CO_2 and NOx with an average savings of up to 1.5% and 3.2% respectively and with a saving up to 2.7% and 4.1% in rural conditions. The App significantly reduced fuel consumption on average by 2.5%. The haptic systems reduced fuel consumption by an extra margin of up to 3% as compared with a purely visual system.

3.4.6 Main findings — driver workload and attention

WORKLOAD

- When using an ecoDriver system, driver workload will increase
- Workload varies across the different ecoDriver system types

There was no evidence to suggest that any of the ecoDriver systems tested caused a substantial increase in subjective driver workload. Across all system types, there was only a very small increase in total workload when interacting with the system, with some tentative evidence to suggest that workload may have decreases with increasing exposure.



ATTENTION

- Using an ecoDriver system with in-trip feedback, the drivers are more distracted
- In-car feedback from the ecoDriver system cause inappropriate/dangerous visual behaviour, in terms of glances towards the device
- Using an ecoDriver system, the driver will look more at the speedometer/rev counter

Most systems tested had a visual user interface aimed to attract visual attention. Attentional effects were investigated with only the FeDS. The overall time spent looking away from the forward roadway was found to be larger with the FeDS. However, drivers did not neglect to glance at the mirrors or speedometer, and data obtained from motorway driving indicate that glances towards the FeDS did not exceed the available visual spare capacity as determined by a visual occlusion study. Glance patterns indicated that drivers were anticipating feedback from the FeDS, which indicates that the HMI could be improved to reduce workload. Thus, it is advisable to integrate the eco-support system with the speedometer.

3.4.7 Main findings — driver speed

SPEED

- Using an ecoDriver system the average velocity when cruising will be lower
- Using an ecoDriver system the average free velocity will be lower
- Using an ecoDriver system, speed will change when driving before locations where a low speed is recommended by the system

i. **Across all systems,** cruising speed in the controlled drives reduced by 3.4% on motorways and 4% on rural roads. The naturalistic data also show a reduction in cruising speed, by up to 3.3%. Average speed when free driving was reduced by about 3% for the controlled studies alone. Speed reduced in advance of intersections and speed limit decreases in rural and motorway conditions. Speed reduced before sharp curves and zebra crossings in rural conditions.

ii. **Comparing the results across road types,** speed reductions were observed mostly on rural roads and motorways for the controlled drives (4% and 3.4% respectively), with a similar reduction (3.3%) observed for the naturalistic data on urban roads. Potential benefits exists for both rural and urban road types when systems alert for infrastructure constraints.

iii. **When grouping the systems by categories** the embedded systems provided strong evidence of a cruising speed reduction of 1.5% to 3.5% in all conditions, while the App did not show any significant effect. The haptic systems obtained an *additional* 3.6% reduction. A reduction of cruising speed of 8.5% on urban roads was found. Free driving speed was also reduced by around 10% in urban areas with the embedded systems. Around events, the embedded systems produced speed reductions of up to 6.3%, with the largest effects observed in advance of a speed limit change and on the approach to intersections.

3.4.8 Main findings — time headway

THW DISTANCE / SITUATIONS

- Using an ecoDriver system, the time headway distribution to leading vehicle will change
- Using an ecoDriver system, there will be shorter distances to vehicles before safety critical locations

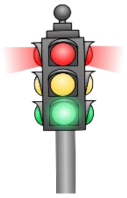
i. **Across all systems,** time headway increased on average by 6.3%. The systems had no impact before zebra crossings, speed bumps and crests, but time headway increased by up to 8.1%

before intersections. The systems also increased time headway before speed limit changes by 5.4%.

ii. **Comparing the results across road types,** average time headway increased globally for every road type. Overall effects on time headway were particularly strong for the FeDS on motorways. Before intersections, haptic systems show the greatest effects on all road types (15.2 %).

iii. **When grouping the systems by categories** benefits came only from the embedded systems and for the FeDS itself, increasing average time headway by up to 22.3% on sharp urban curves. Those systems without radar (ecoDriver App and the haptic systems) were unable to have an effect. Significant impacts were observed before intersections (13.9 %), sharp curves (22.3 %), and speed limit changes (16.8 %).

3.4.9 Main findings — driver behaviour in events



EVENTS

- Using an ecoDriver system, there will be more red or amber light violations
- Using an ecoDriver system, there will be fewer overtakings

Events such as red or amber light violations during the controlled trials proved very difficult to observe in a reliable way. The number of overtaking manoeuvres were observed at an identical rate in the baseline and treatment phases, while fewer speeding events were observed when using embedded systems.

3.4.10 Main findings — the four golden rules

4 GOLDEN RULES

- Using an ecoDriver system, the average rpm when shifting up will be reduced
- Using an ecoDriver system, the weighted average engine rpm will be decreased
- Using an ecoDriver system, the variability of speed profiles will be decreased
- Using an ecoDriver system, the use of the engine brake will be improved

i. **Across all systems,** in the controlled drives, positive impacts on the rules of eco-driving were observed, by up to 9.7%. The use of the engine brake improved only on rural roads. Results were more variable for the naturalistic drives, but still overall positive for average rpm when shifting up (3%), weighted average engine rpm (3%) and PKE (5%).

ii. **Comparing the results across road types,** in the controlled drives, positive effects of the systems are observed on every road type, although weaker on motorways. No significant change was observed in engine brake use for urban and motorways. Even for embedded systems, there was no significant change in speed profiles on motorways.

iii. **When grouping the systems by categories** the haptic systems did not induce any changes whilst the embedded systems, including FeDS, succeeded in generating driving behaviour compliant with the golden rules. The ecoDriver App also generated green driving behaviour, but less saliently than the embedded systems. The use of the engine brake increased with both the FeDS (5.1%) and the App (6.4%), but only for rural roads. The App tested under naturalistic driving conditions was effective for all rules, except for the use of engine brake.

3.4.11 Main findings — acceleration and deceleration

ACCEL DECEL / SITUATIONS

- Using an ecoDriver system, the high accelerations will be reduced
- Using an ecoDriver system, the hard deceleration will be reduced
- Using an ecoDriver system, acceleration after being stationary will be less aggressive
- Using an ecoDriver system, the acceleration distribution will change before locations where a low speed is recommended by the system

i. **Across all systems,** there were improvements in acceleration: a change of about 10% was found in reducing 95th percentile of acceleration, 5th percentile of deceleration, and maximum acceleration. The naturalistic data deliver a different picture: high accelerations and decelerations were reduced on urban roads, but they increased on rural roads and motorways. Once again, the main benefits are observed for embedded systems, and for urban and rural roads. Neither the haptic systems nor the App softened deceleration before specific situations.

ii. **Comparing the results across road types,** large benefits can be expected on urban and rural roads, but not on motorways. For deceleration at the specific situations, the impacts were similar for urban and rural roads. The observed changes were more linked to the situation type than to the road type itself.

iii. **When grouping the systems by categories,** neither the App nor the haptic variant generated any significant benefits. In controlled drives, only the embedded systems generated softer acceleration and deceleration. The nomadic eco-driving systems had an impact when used in naturalistic driving in urban areas. For deceleration at the specific situations, the main benefits came from the embedded systems such as the FeDs.

3.4.12 Overall conclusions

Within ecoDriver, several different systems were tested with different characteristics and features. The only systems we can isolate are the ones developed solely within the project: the FeDS and the ecoDriver App. These two systems are very different despite their apparently similar HMI. Other systems did not share the same HMI nor the same approach to encouraging eco-driving behaviour.

As a global picture of the ecoDriver results, it is confirmed that embedded systems (including FeDS), provide more benefits than nomadic systems such as the App. Embedded systems perform better because of their integration into the vehicle and the ability to use vehicle data information to display advice. On the other hand, non-embedded systems such as the App rely on internal computation mainly based on GPS information. It is therefore not surprising to observe this difference. Adding a haptic pedal can be useful, and produces small benefits, in the direction of greener driving. Although usually non-significant, these results confirm that such a feature can be an important element of a larger system, and can increase acceptability. The poor performance of the App on controlled drives is counterbalanced by some positive results during the naturalistic experiment, especially in saving energy.

The main findings of this study can be summarised as follows:

- Using ecoDriver systems in real conditions, and applying a conservative statistical approach, energy savings ranged from 2% to 6%. This is less than aimed, but closer to the reality.
- The ecoDriver systems proved to have strong positive impacts on speed, time headway, and accelerations and decelerations. This could translate into less severe crashes.
- The ecoDriver systems proved to generate a driving style compliant with the golden rules of eco-driving.
- Advice on eco-driving in specific situations generates a change in driving behaviour. This change is closely related to the quality of the system (integration, precision, reliability, HMI).
- Nomadic systems change the driving behaviour in a good direction, but benefits are smaller than when using an embedded system.
- The naturalistic experiments gave different results than the controlled studies. Although not comparable (only the App was used in both types of studies), these differences deserve deeper investigation.
- Naturalistic experiments are recommended to study the long-term impact of eco-driving. A change in driving style was observed even when using a nomadic system; safety or energy benefits can therefore be expected in case of large-scale dissemination.

3.4.13 Lessons learned from the on-road trials in the ecoDriver project

The ecoDriver project was a collaborative project, in the sense that all partners have engaged together to share their collected data into a common database. The research questions list have been divided across partners, so that each partner is in charge of analysing one aspect, using data from all partners. It has been decided to use open source software (R software) for statistical computations. This improved the reliability of the approach by guaranteeing the consistent use of the same methods and algorithms. The adopted approach was different from that of previous FOTs in which each partner was in charge of analysing its own data collected during their trials. Although successful, this approach revealed other drawbacks that may require further attention for the upcoming projects. These are can briefly be described as:

- Adopt a single experimental design for all experiments,
- ensure project partners accept to share the data required for the analysis,
- work in close collaboration between database managers and data scientists,
- agree on a Gantt chart for the whole data management chain and schedule a time margin for unpredictable delays,
- take care of the confidentiality of collected data in the data management process,
- use common open source tools and methodology, and share the code,
- automate the statistical analysis process, from code to formatted tables,
- do not underestimate the time needed for database computations,
- adopt a statistical methodology in line with current standards,
- plan theoretical and practical workshops about statistical methodology before starting to analyse data,
- scaling-up of the results should be scheduled sequentially after the statistical analysis is completed.

3.5 How does the ecoDriver assistance affect the traffic system?

3.5.1 Scenarios of the future

The share of vehicles equipped with the ecoDriver systems can be assumed to increase over the future years, from a low percentage in the year they are introduced to moderate or high levels depending on which direction the future takes. A scenario based evaluation approach was taken to enable evaluations of the effects on the traffic system not only for the introduction year but for up to 20 years into the future for three different possible future scenarios. The scenarios used were called Green Future, Policy Freeze and Challenging Future. Policy Freeze is the closest to a 'Business-as-Usual' scenario, whilst Green Future and Challenging Future present alternatives on either side of this. Green Future assumes high fuel prices, supportive attitudes and policies and fast technology development. Challenging Future assumes low fuel prices, unsupportive attitudes and policies and slow technology development. Market penetration rates of ecoDriver systems are assumed to vary over time and across scenarios: projections including both embedded systems and low-cost mobile-app-based systems reach between 45% (Challenging Future, for cars) and 79% (Green Future, for cars) by 2035. Projections were also done for drivers' compliance with the ecoDriver systems' advice: assuming up to 92% of the car drivers to be fully compliant by 2035 in the Green Future; and down to 60% of the car drivers to be fully non-compliant by 2035 in the Challenging Future.

3.5.2 Modelling the scenarios

The traffic system impacts of the scenarios were quantified by means of traffic simulation modelling at a microscopic level for small networks. For each scenario, three different road environments (i.e. motorway corridors, rural roads and urban street networks), were modelled and simulated. Different road designs were considered within each road environment. The full set of networks included: urban and interurban motorway; flat and hilly rural roads with low or high intersection density; and flat and hilly urban roads in a compact or spacious city. To facilitate analysis of development in the scenarios over time, models of the road environments for every fifth year up to 20 years into the future was created and simulated. The scenarios are assumed to have a common starting point in 2015 for which the penetration rates of ecoDriver systems are assumed to be zero. There were in total 48 different cases for each simulated road network (3 scenarios times 4 future years times 2 traffic demand levels with and without ecoDriver systems).

Microscopic traffic simulation is a common tool for estimating impacts of driver support systems on the traffic system. However, current state-of-the-art microscopic traffic simulation modelling do not handle driver behaviour effects of driver support systems. Hence, existing microscopic traffic simulation models need a supplement to handle the functionality of driver-support systems and the changes in driver behaviour that these systems may induce. To manage this, a traffic simulation framework that includes separate modelling of the ecoDriver system and the driver's interaction with the ecoDriver system was developed. The framework consists of four main parts: a Traffic Simulation program**;** an External Module handling the ecoDriver systems and drivers interaction with the systems, a traffic simulation program specific Application Program Interface which handles the connection between the traffic simulation program and the external module, and a Performance Indicator calculation module.

The external module consists of three modules: a model of the ecoDriver system(s); a Driver Model; and a Vehicle Model.

The ecoDriver system module are vehicle class (passenger car, van, truck) and powertrain (petrol/diesel, hybrid, electric vehicle) specific models of the ecoDriver system that were developed in the project. The ecoDriver models generate speed and gear advice to the drivers. The driver models simulate how drivers respond to that advice, in particular their compliance with the speed and gear advice under different circumstances. These models are based on data collected in the field tests. The drivers' choices (speed, acceleration, gear) are fed into a simple vehicle model that determines the engine speed and whether the vehicle can deliver the requested acceleration. The data are then fed into the simulation model which updates the vehicles' positions. This way, vehicle trajectories and aggregated statistics are generated, which are used to determine the impacts of the ecoDriver system on traffic performance (e.g. travel times), traffic safety (e.g. risk of fatal incidents), and the environment (energy use and emissions). Safety effects were estimated using the speed power model (Elvik et. al. 2004) while energy usage and emissions were estimated based on an already available emissions database (Ligterink et. al. 2014).

3.5.3 Results of the modelling

The results indicate relatively moderate savings in CO_2, NO_x and energy consumption, large safety savings but also rather large increases in travel time. The CO_2 savings are smaller than the average savings found in the field trials, which is natural since the field trial results only include savings from equipped vehicles while the traffic simulations present the average saving for a mix of equipped (Embedded and Nomadic) and non-equipped vehicles.

The savings are in general largest on the rural roads, somewhat lower on motorways and there is in principle only safety effects in the urban setting. This is quite natural since all the types of advice (speed, gear and upcoming lower speed limit) appears and may influence the drivers on the rural roads. Motorway driving commonly imply driving at the highest gear, thus gear advice is not frequent. The number of speed limit changes is also less frequent on motorways. Thus, the main contributing part on motorways is the speed advice. Urban road driving implies more frequent gear changes while the possibility to freely choose the speed and for speeding is more limited. The main contributing part on urban roads is therefore the gear advice.

Figure 15 shows the CO_2 results for motorways and rural roads, for cars, vans and trucks (buses were not simulated explicitly for these road types, as their share is very low, but they were assumed to behave similarly to how trucks behave), and for the flat networks with low demand. The scenario considered is the Green Future scenario, in 2035. This is the scenario with the largest effect sizes (because of relatively high penetration rates and compliance). The CO_2 emissions decreased on all road types; the largest decrease found was over 8%. On motorways, the largest effects can be found for trucks due to a substantial decrease in speed (in the without case, most trucks are assumed to drive at speeds over the speed limit of 80 km/h; for cars and vans a much smaller share of vehicles is assumed to drive at speeds over the prevailing speed limit). On rural roads, the largest effects are for cars and vans. Overall, the effects are larger for rural roads, as cars have by far the highest share in the traffic composition (for motorways, the car share is approximately 85%).

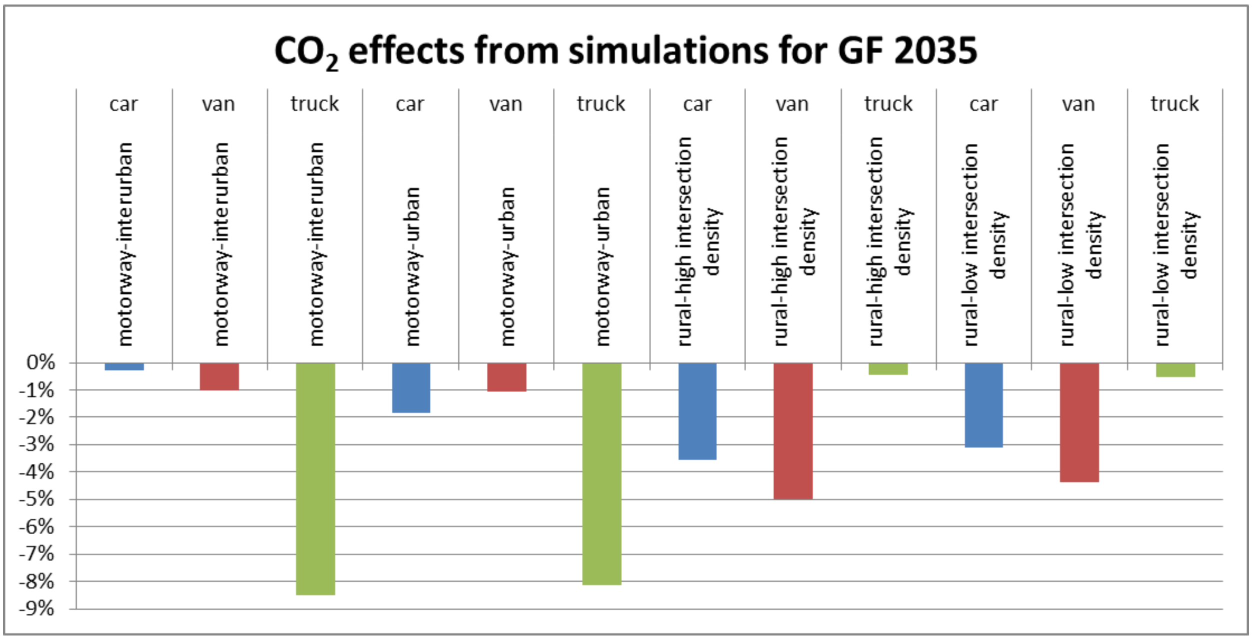


Figure 16: CO_2 effects from the simulations, motorways and rural roads (car/van/truck, flat, low demand)

For fuel consumption and energy consumption, the effects are very similar. For NO_x, the effects are somewhat different, because in the motorways and rural roads simulations some unexpected and rather large increases in emissions were found for trucks. These increases could not be explained in a satisfactory way, but could be caused by the nature of the emission model used (a regression model). The aim in ecoDriver was to apply a model that reflects reality as much as possible, i.e. based on real-world measurements (as opposed to chassis dynamometer measurements). However, there aren't enough real world measurements yet to answer this discussion. We've tried to use the best possible data (based on raw measurements), but they're just now started to be collected. It has become clear that models based on chassis dynamometer measurements also have weaknesses. Thus, there is a need for further research and development of real world driving based energy and emission models. One also have to bear in mind that emissions from trucks is complex and depend on for which payload in relation to engine power and speed level that the engine is optimised for. Furthermore, the performance indicator used in ecoDriver is NO_x in g/km. Cruising at a higher speed means that the vehicle needs a shorter time to travel each kilometre. So even if the emissions per second is lower at a lower speed this does not always imply that the emissions per kilometre is lower. The NO_x results have been included in the scaling up and CBA (and the uncertainties about the NO_x results have been accounted for in a sensitivity analysis).

For hilly roads, the effects are in the same order of magnitude as for flat roads. When comparing low and moderate demand situations, the effects are slightly smaller for moderate demand situations on rural roads. For motorways, the differences between low and moderate demand are very small.

Figure 16 shows the uncorrected travel time effects. The travel times increase in all cases. On motorways, truck travel times are most affected (because of the reduced speed). On rural roads, all vehicle classes are affected. When corrected for speeding, the travel time effects are much smaller (going from several % when uncorrected to almost 0% when corrected).

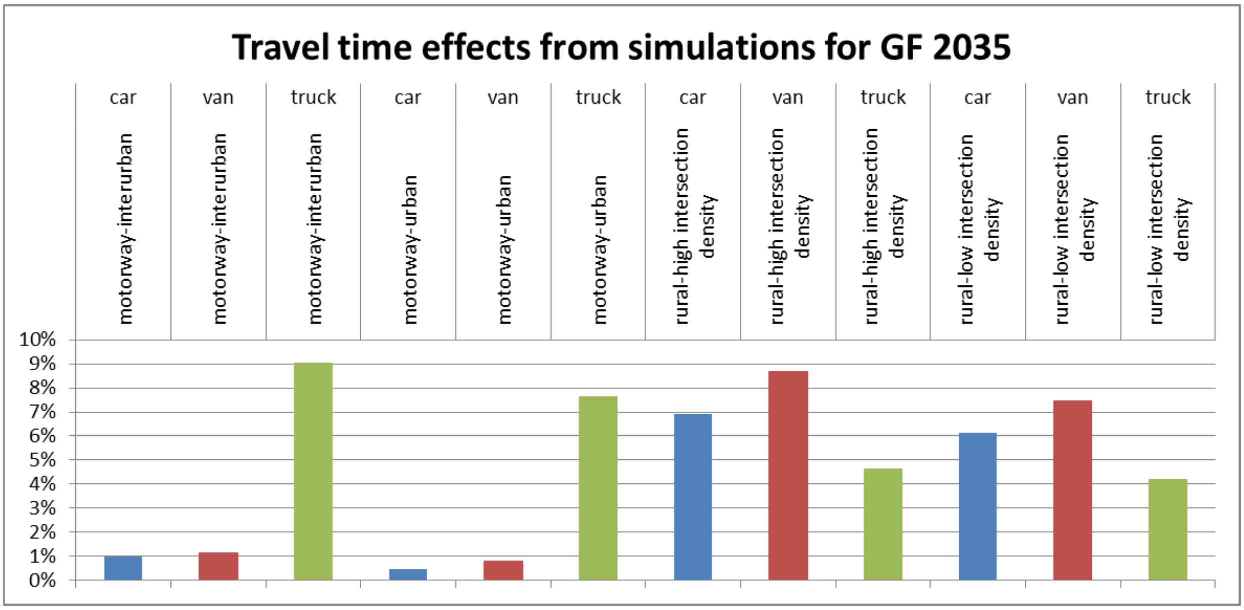


Figure 17: Travel time effects from the simulations, motorways and rural roads (car/van/truck, flat, low demand)

Figure 17 shows the safety effects. These were calculated using the Power model (Elvik et al., 2004) for all vehicle classes combined. The safety effects are large, compared to the other indicators, and are largest on rural roads, with the number of fatal accidents/fatalities being reduced the most (20-25%). Since there are no significant effects of the ecoDriver system on speeds for urban compact roads, there are no safety effects on these roads.

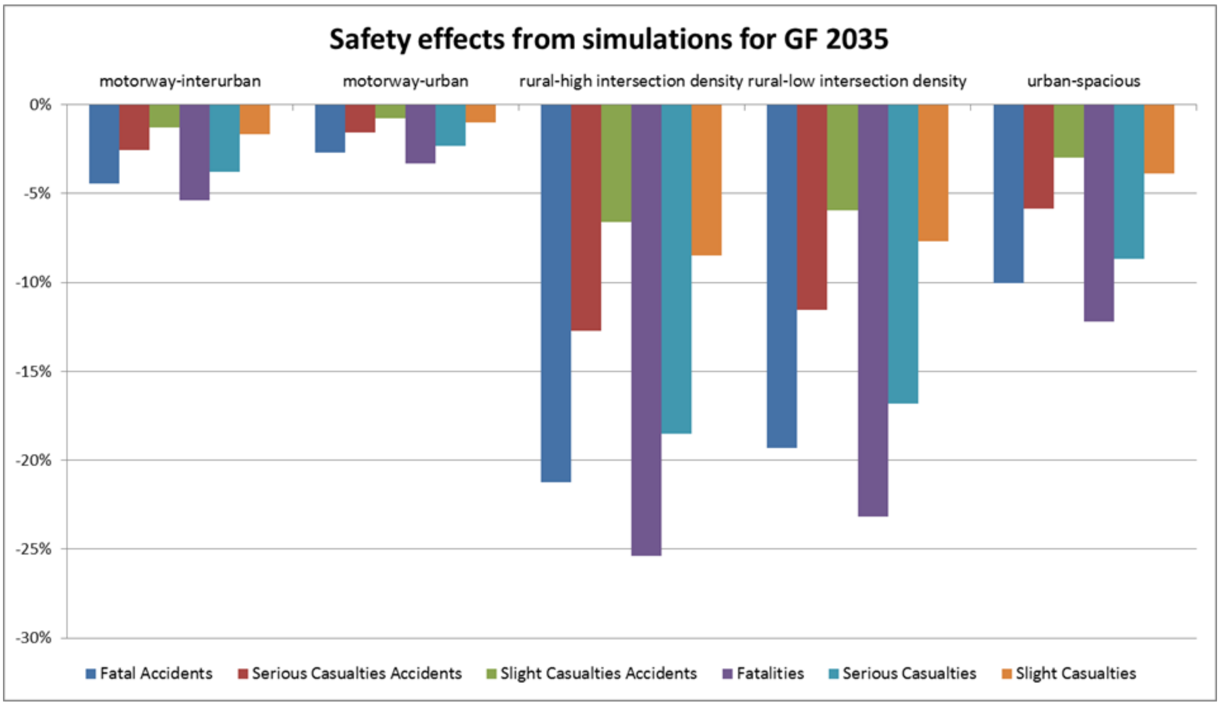


Figure 18: Safety effects from the simulations on motorways, rural roads and urban spacious roads (car/van/truck/bus, flat, low demand)

3.6 Conclusions from the R&D

The real-world trials of the various ecoDriver systems revealed that:

- The project had created an effective HMI design which secured good driver compliance while maintaining attention to the road and traffic
- Energy calculation performs better and produced better advice to the driver if it has access to real-time vehicle-based information
- In the FeDS, the project created a highly capable energy calculator that can assimilate a large quantity of information and recalculate fast, but the vehicle manufacturers have an in-built advantage here in terms of their extra knowledge
- In terms of observed driver behaviour, the systems secured good compliance and produced significant energy savings, as well as substantial improvements in speed compliance, with predicted large safety benefits. The more sophisticated systems tended to encourage greater savings in energy. Overall reduction in observed energy use averaged 4.2% with a higher impact of 5.8% on rural roads. In terms of speed, there were reductions of up to 4% in cruising speed and on the approach to events such as sharp curves. There was an additional effect from providing feedback via a haptic throttle.

A substantial effort in the project was devoted to exploring the wider impacts of the systems on traffic and the environment under a range of scenarios of the future. This allowed the calculation of the costs and benefits of the systems. That modelling of impacts revealed that:

- Widely deployed, the project's systems could make a real contribution to CO_2 targets for transport
- There would be substantial impact in terms of saved fatalities and injuries as a result of the observed changes in vehicle speed

It should be noted that the projects advice to drivers was not maximal, i.e. it did not always advise a speed choice that would maximise the energy savings. A balance needs to be struck between the theoretical optimality of advice in terms of energy savings and its acceptability to drivers. It was considered that there would be low acceptance to advice that suggested driving well below a high speed limit. Therefore the decision was made that advised speed should be 100 km/h for speed limits over 100 km/h.

4. Potential impact, dissemination and exploitation of results

4.1 Impact

The potential socio-economic impact of the ecoDriver systems have been examined by scaling up the field trials results to the EU-28 level via a set of traffic simulation experiments for a set of representative networks (see Chapter 3.5). Figure 18 - Figure 20 show the scaled-up effect sizes for each of the three scenarios, for the year 2035 (effects are also available for the years 2020, 2025 and 2030). The figures show the % change between a situation with and without ecoDriver. The effect on emissions and energy consumption is as intended (a decrease) but quite small at the EU-28 level. The size of the effects varies from a decrease just above 0% to about 1.7%. Effects are largest for the Green Future scenario and smallest for the Challenging Future scenario. Rural roads contribute the most to these effects, because rural roads have the highest effect sizes and the highest share in total EU-28 mileage (as compared to motorways and urban roads).

The figures show that the safety effects are quite large compared to the environmental and traffic efficiency effects. Also, the effects are clearly the largest in the Green Future scenario. This scenario has the highest penetration and compliance rates of the three (as well as the highest share of environmentally friendly vehicles). The effect sizes at the EU-28 level are smaller than the ones found in the simulations, because ecoDriver is assumed to have no effect in congested traffic (where the ecoDriver advice is generally not relevant, e.g. advice to slow down for a lower speed limit). They are also smaller than the effects found in the field trials, because the scenarios assume lower than 100% penetration and compliance rates.

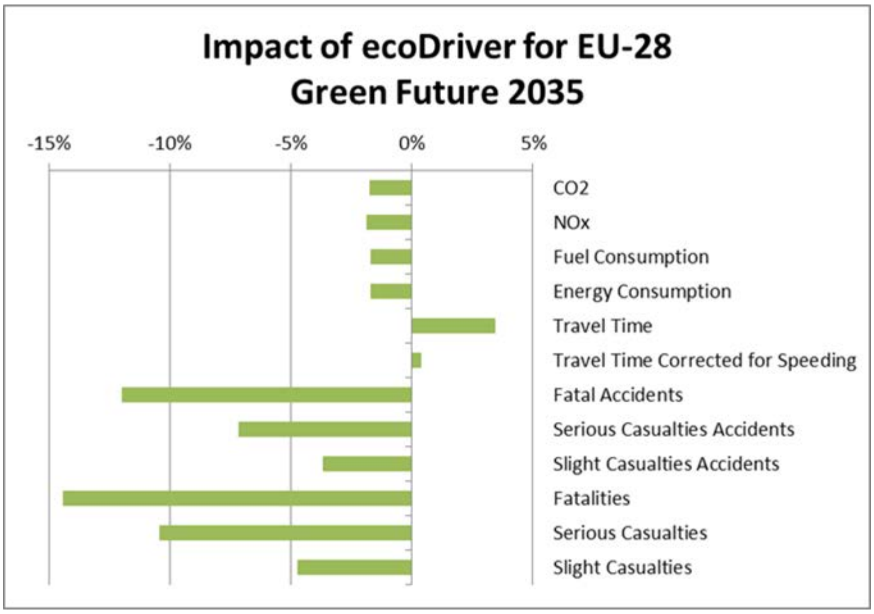


Figure 19: Impact of ecoDriver systems for scenario Green Future 2035, for EU-28

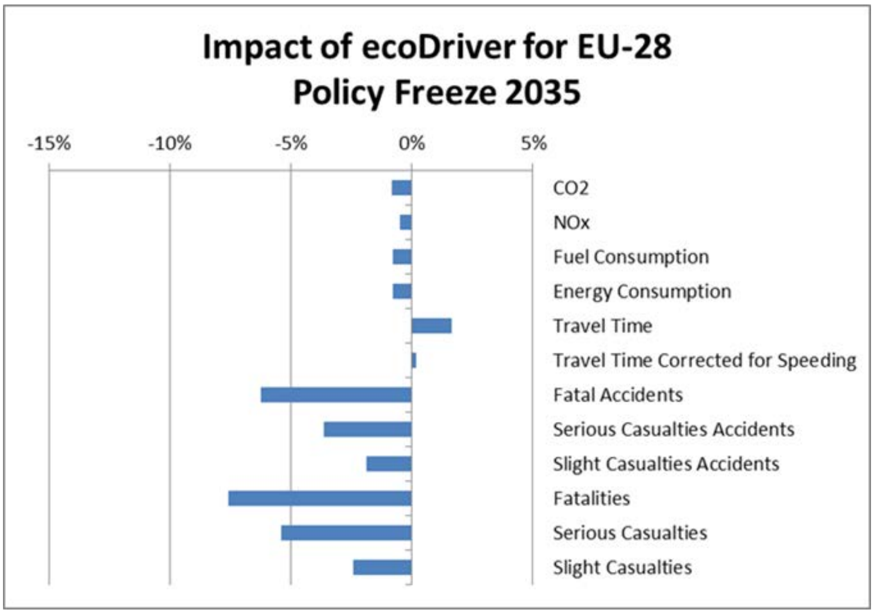


Figure 20: Impact of ecoDriver systems for scenario Policy Freeze 2035, for EU-28

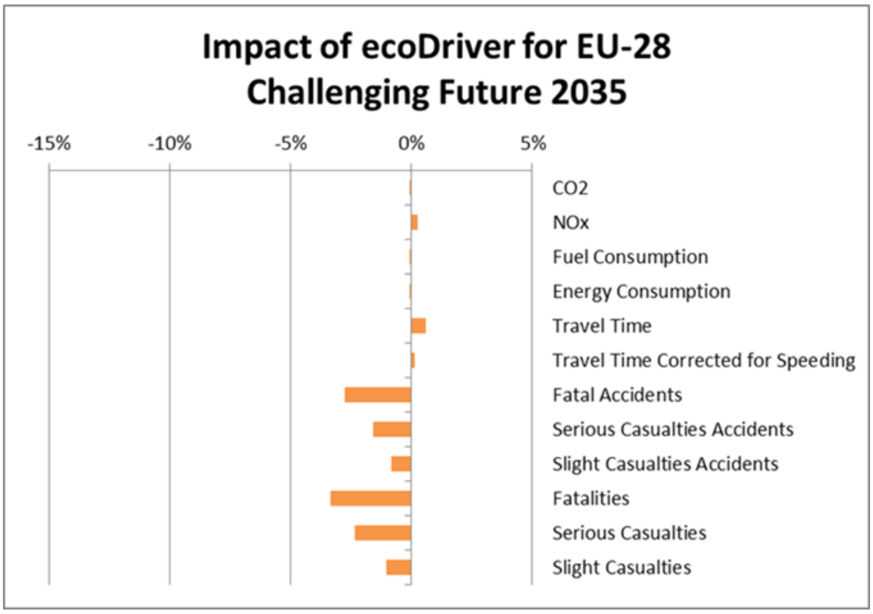


Figure 21: Impact of ecoDriver systems for scenario Challenging Future 2035, for EU-28

The scaled up results were used in to order to conduct a cost-benefit-analysis (CBA), which used established methods that have previously been used to appraise EU transport policies and projects. The approach followed the FESTA Handbook (FOT-Net, 2014) and adopted the latest research evidence and valuation guidance for the EU. It is a scenario-based CBA: we tested not only whether ecoDriving is a good investment in a Business-As-Usual type world (the 'Policy Freeze' scenario), but also its robustness to a widely supportive future scenario ('Green Future') or in a widely unsupportive one ('Challenging Future'). The analysis contained both a Social CBA and a Stakeholder CBA.

The overall benefit:cost ratio is considered to be good for the Policy Freeze and Green Future scenarios at around 2. For the Challenging Future scenario the costs are greater than the benefits: the BCR falls below 1. The stakeholder CBA shows that we can be reasonably confident the system is worth purchasing for drivers. This depends not only on their own fuel saving but also on whether other benefits are big enough, because there are substantial time losses which weigh on the driver and because there are some substantial benefits which accrue, in part, to 'others' on the road, i.e. the safety benefits. For buses and trucks, the case for the ecoDriver system is very positive. Also for a representative European diesel car with the typical mileage, the fuel savings would easily justify purchasing the ecoDriver system.

The results from the field trials show that the effectiveness of the ecoDriver system could be twice as high as the effects found in the traffic simulations, if the implementation of the ecoDriver system is optimised further. Assuming that a version of the ecoDriver system can be developed that enables drivers on the road to achieve that increased level of fuel/energy and CO_2 savings, we have carried out a sensitivity analysis of the CBA results to determine what that would mean for the benefit:cost ratio and other CBA results. The impact on the Net Present Value (NPV) is strongly positive, whilst the BCR to government remains just 'good' – this is because the cost to government increases due to loss of indirect tax revenue (fuel taxes).

It is unclear if these extra savings would be achieved by driving at lower speeds (lower than found with the version of ecoDriver that we evaluated in the project), which would mean that there are also other effects, such as on travel times and safety, that need to be quantified. It is also not clear whether a more effective version of the ecoDriver system would need additional hard- or software (such as a haptic gas pedal) and what this would mean for the costs of the system. However, if the ecoDriver system can be engineered to achieve higher benefits at a cost of €250 per unit for the embedded system (the 'FeDS', whilst the mobile app would have a nominal €15 charge and a correspondingly lower level of performance) then the case for several stakeholders looks stronger.

The scaling up and cost-benefit analysis provided valuable insights into the impacts of ecoDriver on the EU-28 level, and showed that, in all the scenarios explored, ecoDriver systems have the potential to decrease energy use and emissions, and the number of accidents and casualties.

The **overall conclusions** were:

- The benefit-to-cost ratios of adoption of the systems are excellent
- As indicated by the scenario analysis, there is a need for the relevant authorities to promote these systems, if they are serious about achieving their environmental targets

4.2 Dissemination

4.2.1 Aims

Dissemination and communication in ecoDriver was led by ERTICO (WP2 leader) but included the active involvement of all partners. The purpose, as set out in D2.1 Dissemination and Communication Plan, were to:

- Raise awareness and understanding about ecoDriver, particularly among the target groups;
- Involve relevant stakeholders in certain project activities in order to obtain their feedback;
- Stimulate the establishment of networking activities with similar projects in Europe and beyond;
- Promote the dissemination and exploitation of the project results;
- Raise the profile of project partners.

A general audience was targeted, but most specifically experts in green driving, sustainable mobility, HMI issues, and ITS in general. This includes vehicle manufacturers, system providers, researchers, transport/fleet operators and public authorities. In addition, journalists and the media in general were targeted. Furthermore, as the consortium includes educational institutes, the project provided an opportunity to engage students and young researchers.

Standard communication elements developed in the project included the project logo, a grid of the logos of all 12 partners (updated with changes during the project) and some standard graphics, which were used in brochures and on the project website.

4.2.2 Website and social media

The main communications tool throughout the project was the website, at www.ecodriver-project.eu.

The website features the most recent news items on the homepage, along with two boxes for other stories (Final Event and videos in the above example). The site's "About" section gives the project description, organisation and consortium details, "News" and "Events" are regularly updated (with an archive of past events included), whereas "Library" includes all approved deliverables, brochures and videos, as well as a "clippings" section containing items about the project from other media sources.

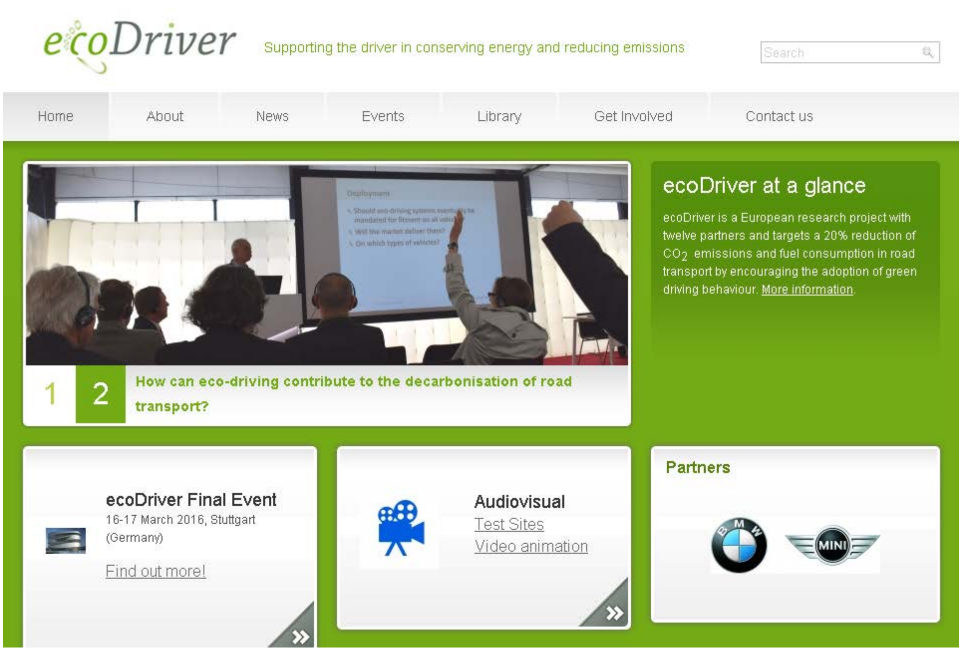


Figure 22: Website home page

News items were posted regularly (approximately every two months, but variable according to news generated by the project). In total, 34 news items about the project were posted on the website. Events involving or related to ecoDriver were also publicised on the website: 24 events in total including the ecoDriver Final Event.

Average monthly website visits per year have evolved as follows:

Table 10: ecoDriver website monthly visits 2013-2016

Year	2013	2014	2015	2016 (1 Jan-30 Apr)
Total mean visits per month	315	351	517	777
Mean visits per month over 1 minute duration	77	88	108	188

For the last full year of the project (April 2015 to March 2016), 72% of website visits were from new visitors and 28% were repeat visits. Average time on the site was 2 minutes and 24 seconds. The countries generating the most visitors were (in order) Germany, Belgium, the Netherlands, UK, USA, Italy, France, Spain and Sweden.

The website was supplemented by an ecoDriver group on the LinkedIn network. This group replaced an initial mailing list or “Forum”, as it allowed two-way communication and allowed short items to be posted which may not warrant a full newsletter. Currently it has 175 members, of which 80% are external to the project. Membership is open to all interested people and short news flashes on the project's progress and events are provided. The LinkedIn group has been regularly used to promote links to new material on the project website and to promote ecoDriver events.

Other media has been used to distribute ecoDriver news:

- The ERTICO Network (www.erticonetwork.com) as well as weekly e-bulletins to which anybody can subscribe for free.
- Websites of partners.
- Social media of partners, for example:
  - ERTICO: www.youtube.com/user/intelligentransport, https://twitter.com/ertico, www.facebook.com/ErticoNetwork
  - University of Leeds Institute for Transport Studies: https://twitter.com/itsleeds, www.facebook.com/InstituteforTransportStudies
  - TomTom Telematics: https://twitter.com/tomtomwebfleet

4.2.3 Events

The project organised and participated in several workshops, conferences and other events, as follows:

Table 11: List of past events organised by ecoDriver or where ecoDriver participated

Name of the event	Date & location	ecoDriver role
ITS World Congress 2011	22-26 October 2011 Orlando, USA	David Sanchez (CTAG) delivered the presentation "The ecoDriver project" in the special session "Eco-driving: a key enabler for future clean and efficient mobility worldwide"
EUCAR Annual Reception and Conference	8-9 November 2011, Brussels, Belgium	ecoDriver poster session
ITS World Congress 2012	22-26 October 2012, Vienna, Austria	ecoDriver participation in special session "Human-machine interfaces to encourage an environmentally friendly driving behaviour" on 24 October. ecoDriver lunchtime workshop on 25 October
ITS European Congress 2013	4-7 June 2013, Dublin, Ireland	eCoMove-ecoDriver joint stakeholder workshop on 4 June: ecoDriver presentations from Samantha Jamson (University of Leeds) and Isabel Wilmink (TNO). Special session on 7 June: "Eco-driving – How to keep performances on the long term?" organised by Jean-Charles Pandazis (ERTICO) and moderated by Oliver Carsten (University of Leeds)

Name of the event	Date & location	ecoDriver role
Driving Assessment Conference 2013 (7th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design)	17-20 June 2013, New York, USA	Hamish Jamson, Daryl Hibberd and Natasha Merat from the University of Leeds, presented a paper titled "The design of haptic gas pedal feedback to support eco-driving" during the session dedicated to driver performance and simulation studies.
Webinar presenting the Full ecoDriver System (FeDS)	30 July 2013, online webinar	Presentation of HMI by CTAG
EUCAR Reception and Conference	5-6 November 2013, Brussels, Belgium	ecoDriver 1-page entry into the EUCAR Project Book, also to be used as a poster. University of Leeds presented the ecoDriver results to date
Transport Research Arena (TRA) 2014	14-17 April 2014, Paris, France	Poster session by IFSTTAR and CTAG: "Development of an Ecodriving Assistance Application for Nomadic Devices Performing Real-time and Post-trip Coaching for Road Vehicles"
EC FP7 ICT Call 7 8 Concertation Workshop	30 April 2014, Brussels, Belgium	Presentation by TNO on modelling used in ecoDriver and discussions with related projects (COLOMBO, Amitran, REDUCTION, CARBOTRAF, ICT-EMISSIONS
FISITA World Automotive Congress 2014	2-6 June 2014, Maastricht, Netherlands	ecoDriver paper "Evaluation results of predictive driving advice of green driving support systems" presented by IKA
Stakeholder discussion "In-vehicle applications to help drivers save fuel and reduce emissions"	16 June 2014, Helsinki, Finland	ecoDriver event
ITS European Congress 2014	16-19 June 2014, Helsinki, Finland	ecoDriver paper "and Evaluation Methodology of Green Driving Support Systems" presented by IKA
Transportation Research Board (TRB) 94th Annual Meeting	11 January 2015, Washington DC, USA	Organisation and chairing of Human Factors workshop on green driving
TomTom Telematics event	March 2015, Amsterdam, Netherlands	Launch of TomTom Opti365, emanating from research in ecoDriver. TomTom and University of Leeds participation (invitation-only commercial event)
ITS World Congress 2015	5-9 October 2015, Bordeaux, France	Special Interest Session in the Dissemination stream for the ecoDriver project (proposal accepted). This constituted project milestone MS3 (workshop).
ecoDriver Final Event	16-17 March 2016, Stuttgart, Germany	See description below

The **ecoDriver Final Event** took place at the Mercedes-Benz Museum in Stuttgart, Germany, on 16 and 17 March 2016. This showcase event enabled the project results to be presented and discussed as well as practically demonstrate them to delegates, allowing them to travel in (and drive, if possible) different vehicles equipped with the different ecoDriver solutions. Target audiences included green driving experts and both experts (e.g. from industry or research) and non-expert stakeholders (e.g. on the policy or organisational side, including decision-makers) in Intelligent Transport Systems and/or sustainable mobility, as well as relevant press and media organisations.

The event was widely publicised from September 2015 onwards, including by web, email and a publicity bookmark that was distributed by all partners and at events, most notably at the ITS World Congress in Bordeaux in October 2015. Free online registration for the event was available. Total actual participation (excluding no-shows) was 109 persons (of whom 40 were project partners, including speakers, event management and persons responsible for demonstration vehicles). This exceeded the target of between 70 and 100 persons and in particular all the sessions were well attended.

Figure 24: Final Event publicity materials

Figure 23: Final Event venue in Stuttgart

The agenda was designed to cover the main SPs of the project (SP3 and 4 in one session, as the former covered the on-road trials and the latter was the analysis of the data and evaluation of effectiveness), as well as introductions, keynote speeches, discussions and conclusions. It covered two half days (lunchtime to lunchtime) and was moderated by Dr Yvonne Barnard (Senior Research Fellow at the University of Leeds, Institute for Transport Studies). Keynote introductory speeches were given by high-level guests from Daimler, ERTICO, CRF and TomTom Telematics.

Seven demonstration vehicles were present, enabling delegates to experience all of the different variations of ecoDriver developed in the project (FeDS, nomadic system, TomTom system, embedded systems from OEMs). These are shown in the following table. Delegates could book drives on-site. As the demonstration route chosen was 28km long (in order to cover a suitable range of road types, including semi-rural roads and hilly sections), vehicles generally went out in pairs with passengers changing vehicles at a half-way point, in order to be able to experience a greater range of systems. This arrangement worked very satisfactorily and 74 person-journeys were made over the two days, with 77% of external (non-project partner) delegates taking at least one demo ride.

Table 12: List of demonstration vehicles in Final Event

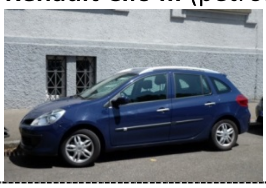
	Vehicle	ecoDriver system fitted (and responsible partner)
1	**VW Passat CC** (petrol) 	**Prototype Full ecoDriver System (FeDS)** demonstrated by IKA (RWTH Aachen University)
2	**Nissan Leaf** (electric) 	**Prototype Full ecoDriver System (FeDS)** demonstrated by CTAG. In addition to the on-road demonstrations, the FeDS in this car was demonstrated in static mode at certain times to show the haptic pedal functionality (this pedal can be rapidly implemented and removed, as it is not legal for public road use).
3	**BMW 535i** (petrol) 	**BMW "ecoAssist" ecoDriver system**
4	**Lancia Musa** (diesel) 	**CRF integrated ecoDriver system**
5	**Mercedes Benz Actros** (diesel truck) 	**Daimler integrated ecoDriver system for trucks**
6	**Renault Clio III** (petrol) 	**Nomadic Smartphone application** demonstrated by IFSTTAR
7	**VW Touran** (diesel) 	**TomTom Telematics OptiDrive 360**

Figure 26: Final Event demonstration cars

Figure 25: Final Event discussion session panel

The presentations from the Final Event sessions can be found at www.ecodriver-project.eu/events/ecodriver-final-event-2. Video footage of certain sessions (where specified at the end of the session/presentation) is available at the above link and on ERTICO's YouTube page (www.youtube.com/user/intelligentransport). An overall Final Event video is also available at these links and further photos of the event are available at www.flickr.com/photos/ertico-its-europe/albums/72157666063421810.

A post-event online feedback questionnaire was answered by 16 external (non-partner) delegates. Overall, nine of them rated the event "excellent", six "good", one "average" and no ratings for "poor". The presentations, demonstration drives, organisation and quality and location of the venue were highly appreciated.

4.2.4 Printed material

A first tri-fold brochure was produced close to the beginning of the project (targeting the wider user community), and a second (interim) brochure was done in 2013, detailing progress to date and explaining the field trials. This was updated in 2015.

Various posters were prepared for events, including seven for the Final Event, mostly describing the functionalities of the systems installed in the demonstration vehicles.

A first brochure (folded colour leaflet) was produced in October 2012 to introduce the project. This was superseded in October 2013 by a 12-page colour A5 format brochure, focusing on achievements to date and presenting the on-road trials and the HMI. An updated version of this brochure was produced in September 2016. These brochures were widely distributed at ITS Congresses and other events.

Other promotional materials were produced including a publicity bookmark and ecoDriver branded pens and bags for the Final Event.

4.2.5 Videos

Several videos were produced, as follows:

- Interviews:

  - Project kick-off interview – text transcript of interview with the Project Coordinator, University of Leeds, October 2011;
  - Powertrain models available for integration in vehicles – video featuring IFSTTAR, May 2012;
  - Importance of driver simulation studies in ecoDriver – video featuring the University of Leeds, June 2012;
  - Contribution of Human-Machine Interfaces (HMIs) to eco-driving – video featuring TNO, June 2012;
  - General presentation of ecoDriver, video featuring the University of Leeds, May 2013;
  - Interviews with partners at seven test sites (VMCs) as part of the video featuring the Real world trials – July to October 2014 (highlights from each VMC visit were posted as news items on the ecoDriver website);
  - Interview with the project coordinator (University of Leeds) on ecoDriver during a TomTom launch event – March 2015;
  - Interviews at the ecoDriver Final Event – March 2016.
- Animation: In 2014 a short animated film (www.youtube.com/watch?v=b-LPfG5BEmM) was produced to introduce ecoDriver from a user's perspective (truck driver and his wife). The story was based on the Storyboard work in WP1.
- The project's major video was released in 2015 and covers the project aims and benefits using footage from the trial sites and explanations from project partners. It involved filming at seven test site locations in six countries. This video (at www.youtube.com/watch?v=KKSfh3LML_c) has achieved over 1100 views and has been particularly useful for sending to persons unfamiliar with the project or the systems developed, as a "newcomer" can obtain a good overview in 7.5 minutes, seeing the systems in use, and without having to read printed documents.
- Final Event highlights video (www.youtube.com/watch?v=pUSg632hh_g) and videos of keynote speeches and discussion session.

The videos are available on the project website and ERTICO's YouTube channel (www.youtube.com/user/intelligentransport), and they were also shown during relevant events.

In addition, ecoDriver features on the Transport Research Innovation Portal (www.transport-research.info) and this project made a video of project with partner IFSTTAR, available here: www.youtube.com/watch?v=B7USY6DLNUE.

4.2.6 Press and publications

Press releases were done at the beginning of the project and at the end for the Final Event, the latter including press releases from ERTICO, the University of Leeds and TomTom Telematics. These led to several articles in the press across Europe, which are collated in the "Clippings and videos" section of the ecoDriver website.

In the run-up to the Final Event, a major article entitled "Drive and ambition" was written on the project in the professional magazine Thinking Highways (http://edition.pagesuite-professional.co.uk/launch.aspx?eid=711011eb-b069-41ff-8f3c-289ded3936d9&pnum=10).

Six papers forming a special issue of Transportation Research Part C (TRC) were published in Elsevier (www.sciencedirect.com) in April 2015, edited by ecoDriver partners led by the University of Leeds. Several papers were also presented at conferences and congresses over the course of the project. These are all available at www.ecodriver-project.eu/library/other-documents.

4.3 Exploitation of results

It is anticipated that the vehicle manufacturers involved in the project will use the knowledge acquired and lesson learned to bring eco-driving systems into series production. One manufacturer, BMW, has already put the coasting function developed in the project and ecoDriver-style HMI into its ECO PRO mode which is provided on various models.

TomTom has released an eco-driving support system as a feature in its Optidrive 360 fleet management and driver support system. IFSTTAR has indicated its intention to further develop and exploit the ecoDriver Android, while TNO has indicated its intention to exploit the VE3 model of energy consumption.

5. Public website and contact details

5.1 Public website

http://www.ecodriver-project.eu/

5.2 Partners

The University of Leeds, UK
BMW, Germany
TNO, The Netherlands
VTI, Sweden
CTAG, Spain
TomTom International BV, The Netherlands
Institut für Kraftfahrzeuge (ika), RWTH, Germany
IFSTTAR, France
ERTICO, Belgium
Centro Ricerche Fiat (CRF), Italy
Daimler AG, Germany
Simotion, Germany

5.3 Core group (SP leaders)

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SP3 leader: Pablo Mejuto (pablo.mejuto@ctag.com)
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SP5 leader : Johan Olstam (johan.olstam@vti.se)

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How to cite this document

Carsten, O. et al. (2016). D1.6: Final publishable summary report. ecoDriver project. Retrieved from www.ecodriver-project.eu