eCoMove

Cooperative Mobility Systems and Services for Energy Efficiency

Deploying the cooperative mindset

Foreword

In 2010, a consortium of 32 partners from across Europe came together to kick off a joint effort to address the problem of energy efficiency in road transport, driven by a vision that:

For any given trip in a particular vehicle, there is a theoretical minimum energy consumption that could be achieved by the "perfect eco-driver" travelling through the "perfectly eco-managed" road network. It should be possible to approach – if not to achieve – perfect eco-driving and perfect eco-traffic management through application of information and communication technologies.

Together the partners started the eCoMove project, "Cooperative Mobility Systems and Services for Energy Efficiency", supported by a grant from the European Commission DG-CONNECT, to realise this vision through development and application of cooperative intelligent transport systems and services, using the latest vehicle-to-X communication technologies.

The project team has developed solutions to reduce inefficiencies responsible for energy waste in road transport: those directly related to the vehicle and to the driver; those related to the trip and those related to traffic management, whose measures influence the way vehicles are driven through the road network and therefore impact on vehicle fuel consumption.

The eCoMove consortium believes that Europe has no choice but to go down the path towards cooperative eco-mobility since every "business-as-usual" prediction seems to lead to an unsustainable future, with more or less severely restrained mobility for all.

eCoMove results will not themselves eliminate congestion, nor will all drivers suddenly improve their performance drastically. However, this project proposes to answer the key questions facing the automotive industry and road operators:

1. **To what extent can eCoMove decrease the fuel consumption and therefore also CO_2 emissions with cooperative technologies?**

2. **Can private and commercial vehicle drivers' performance be significantly and sustainably improved through intelligent cooperative "eco-drive assistance" systems?**

3. **Can cooperative "eco-traffic management & control" significantly improve the fuel efficiency of the ensemble of vehicles in the road network and reduce the aggregate CO_2 emissions over a city or region, or for an interurban motorway network?**

After nearly four years of effort, the project partners are proud to present their results in this brochure. We hope you will share our vision to reduce avoidable inefficiencies, and our determination to see the widespread deployment of cooperative solutions that can achieve a cleaner and more sustainable future for road transport. We invite you to work together with us to realise that vision.

Jean-Charles Pandazis
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ERTICO - ITS Europe

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eCoMove

Introduction

The WHO has recently concluded that air pollution from exhaust fumes and hydrocarbon emissions raises the risk of heart and respiratory diseases. These findings are likely to further increase the pressure on governments to tackle pollution, with transport[1] being one of the main sources.

Transport is responsible for around a quarter of EU greenhouse gas emissions, making it the second biggest greenhouse gas emitting sector after the energy sector. Road transport alone contributes about one-fifth of the EU's total emissions of carbon dioxide (CO_2). Moreover while emissions from other sectors are generally falling, those from transport are continually increasing[2].

The transport sector is therefore the one with the largest potential for emissions savings through Information and Communication Technologies (ICT). ICT applications such as those developed in the eCoMove project, i.e. specifically configured to tackle inefficiencies responsible for energy wastage in road transport, have the potential to achieve a greener mobility of goods and people.

Inefficiencies related to the vehicle (private and professional) and the driver

Inefficiencies related to trip planning and routing (also specifically for freight logistics)

Inefficiencies related to traffic control measures (influencing the way vehicles are driven through the network)

EU roadmap for moving to a low carbon economy

The greenhouse gas emission target set by EU for 2050[3] requires energy efficient vehicles and traffic modes in passenger and freight transport, more efficient transport services and a reduction of unnecessary travel. However we cannot reach this target without the cooperation of all. We must combine our expertise in vehicle technologies, transport services and logistics, as well as the key role of public authorities.

Cooperative systems

Technology and especially next-generation vehicle-to-X or cooperative communications can play an important part in further improving an energy-efficient mobility of goods and people.

Cooperative systems create a "crowdsourcing-type network for traffic intelligence. Vehicles become active sources of near-instant information based on which other vehicles on the road can build a dynamic model of their environment and respond to changing driving conditions faster than typical human reaction times. Vehicles can receive and also send data from and to the traffic infrastructure. An emergency vehicle, for example, can switch traffic lights ahead to green and stop other traffic; or a traffic light could notify an approaching car how long it will stay on green – meaning the driver will not need to step on the accelerator pedal to get through before the light changes. This has the potential to enhance traffic flow efficiency, save fuel, and cut CO_2 emissions." (Lars Reger, NXP Semiconductor)

eCoMove is one of the first initiatives to apply to a new application field (energy efficiency) the results emerging from the previous generation of R&D projects developing the core technologies and early applications based on vehicle-to-vehicle and vehicle-to-infrastructure communication.

By using the emerging cooperative systems technology, it is possible to minimise fuel consumption based on interaction that is twofold:

The urban traffic control system gets real-time insight into the vehicle characteristics through which network control can be optimised;

The urban traffic control system can give feedback on optimal speed advice to individual drivers.

[1] Along with power stations, industrial and agricultural emissions, residential heating and cooking.
[2] http://ec.europa.eu/clima/policies/transport/
[3] EU Roadmap for moving to a competitive low-carbon economy in 2050 aims at 80-95% reduction compared to 1990 levels

Progress against state-of-the-art

Some systems already exist today that support driving in a fuel-efficient way or choosing the route with lower fuel consumption. Certain logistics planning tools incorporate historic traffic information to forecast travel times. Traffic management measures aimed at improving mobility are already applied, which are considered to also improve environmental conditions.

However, to deliver significant improvements, an approach is needed that is explicitly aimed at minimising fuel waste and achieving maximum energy efficiency. Moreover state-of-the-art systems lack the dynamic, real time preview of the traffic situation ahead that V2X technologies can enable. Stand-alone solutions cannot reach their full potential without the communication and cooperation between the different road entities.

Navigation, map and route guidance

Although map data increasingly contains attributes that are essential for accurate fuel consumption estimation (e.g. slope, curvature, speed profiles), these data are not yet used for determining the least fuel consuming route.

Eco-driving support

Several built-in, nomadic or offline systems are already available on the market that provide feedback while driving or post-trip analysis afterwards, but they are not able to take into account the information about traffic light phasing or behaviour of surrounding vehicles.

Basic eco-driving techniques can already reduce fuel consumption without technological support, although the latter can achieve better and long-lasting results.

Fleet management

Fleet planning and routing solutions today are based on historic journey time and other traffic data, with limited real-time traffic information. Tour planning cannot be optimised along the planned route based on real-time events.

Traffic Control & Management

The most advanced traffic control systems for both urban and interurban networks are able to optimise the traffic signal parameters based on historical data, real-time traffic monitoring and short-term traffic forecasts. Traffic state data are mainly collected from sensors such as loops embedded in the roadway, and disseminated to travellers by roadside displays or radio broadcast. No traffic systems available today can manage communication with individual vehicles in order to suggest the lowest-energy route based on network emissions mapping nor the appropriate speed profile to avoid stopping at traffic lights.

eCoMove provides ecoSmartDriving coaching systems that learn drivers' habits and use of fuel, then act as trainers offering advice to improve drivers' eco performance in the long term

eCoMove takes a fresh look at traffic management & control by allowing for a dynamic energy-optimised network management and providing information to vehicles via the roadside to enable eco-routing and eco-driving

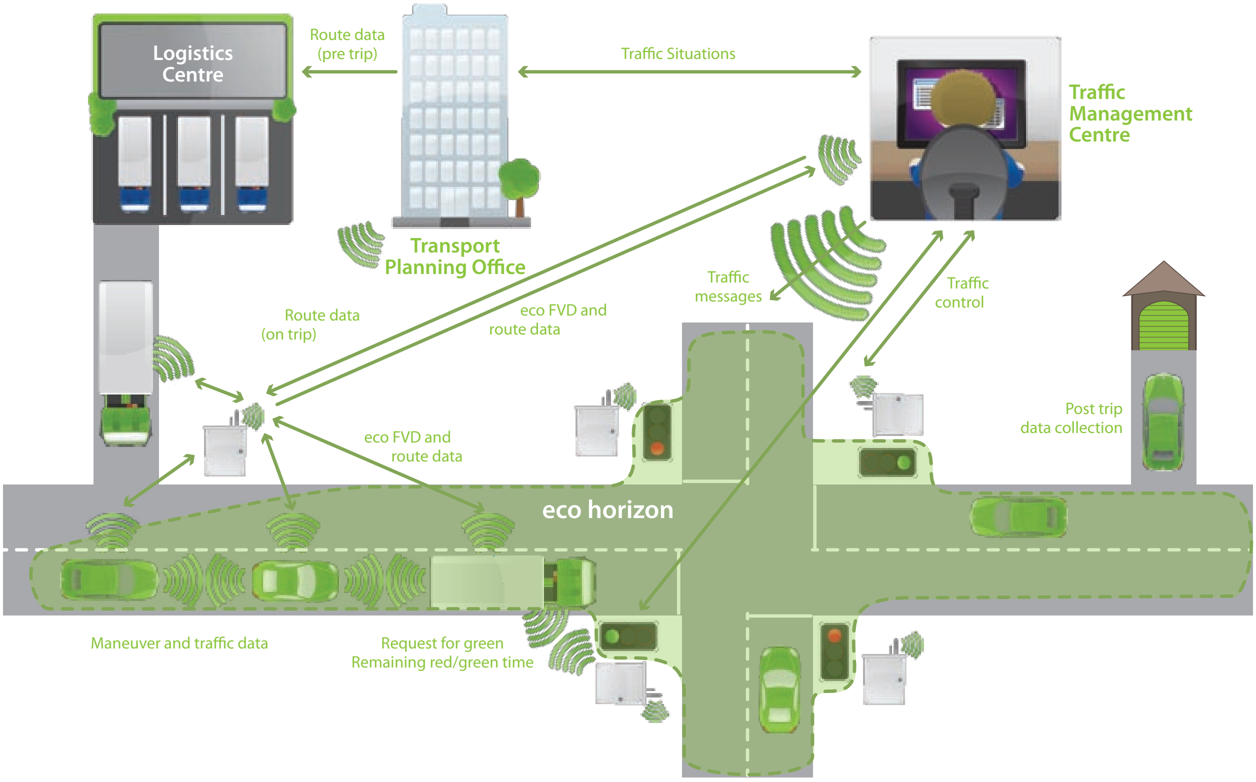
eCoMove takes fleet management systems and truck navigation a step further by integrating cooperative links with the traffic management system to optimise goods transport and planning

Overall system

The essence of the innovation in eCoMove is that all applications are cooperating (i.e. using data from each other) through communication between vehicles and infrastructure to achieve greater energy efficiency and up to 20% reduction in fuel consumption and CO_2 emissions.

eCoMove uses cooperative vehicle-infrastructure systems to collect and exchange energy-relevant data between vehicles and the roadside, to improve the preview of the traffic situation ahead in order to determine the most economical route or way of driving.

When combined and connected to each other in an eco cooperative system, eCoMove applications and services can help drivers, freight and road operators save fuel, unnecessary kilometres driven and manage traffic more efficiently.



Elements of the eco cooperative system

A common vehicle-to-vehicle and vehicle-to-infrastructure **communication platform** for use in vehicles and on the roadside, based on the latest results from European, national and industry projects and compliant with the latest standards

eco messages, protocols and interfaces for information exchange between cooperative entities: eco Floating Vehicle Data (eco FVD) about a vehicle's progress, destination and fuel consumption is collected and disseminated to other vehicles and traffic control centre; eco Traffic Situation Data (eco TSD) about the traffic conditions is sent from the infrastructure to vehicles

A digital **ecoMap** enhanced with static and dynamic eco-attributes, such as slope, historical speed profile and energy consumption data, with also traffic data and information about other vehicles

The **ecoCooperative Horizon** provides the most probable preview of the road ahead taking into account fuel consumption information collected from ecoMaps, traffic management centres and other vehicles, as well as from the dynamic ecoNavigation (which provides the calculated route that is the basis for the ecoCooperativeHorizon Most Probable Path)

An **ecoSituational Model** integrating vehicle driving behaviour and dynamics of nearby traffic to determine the optimal driving strategy and predict how the traffic situation will evolve in the reaction time frame of the driver

An **ecoStrategic Model** translating the knowledge about high fuel consumption factors included in the situational (microscopic) level to the entire road network (macroscopic level), as a basis for traffic management and control strategies

ecoHMI concepts or ecoLanguage translating eco recommendations to communicate in the best way fuel efficient driving strategies (developed individually by each OEM in a way that corresponds to the brand's specific user interface modalities)

Applications calculating and providing support to follow the most efficient route, driving style and traffic control strategies

The underlying theme in eCoMove has been to identify the inefficiencies responsible for unnecessary energy use by road vehicles. To reduce these inefficiencies means finding solutions to:

.....help a driver apply the appropriate actions and driving strategy to use the least possible fuel for a journey by finding the "greenest" route, the most economical use of vehicle controls, the best path through surrounding traffic and how to negotiate the next traffic signals with least chance of stopping;

.....improve truck/cargo energy efficiency by introducing a self-learning "driver coaching system" based on incentives for energy efficiency gains, and a cooperative planning/routing system that selects the most economical route for a truck while the traffic system optimises traffic lights to avoid unnecessary stops;

....allow traffic system managers to adapt traffic signal parameters and apply other control measures so that the ensemble of vehicles in the network consumes the least possible energy, while granting priority at intersections to e.g. heavy fuel consuming vehicles.

Privacy & security

With the emergence of cooperative ITS systems, private data exchanges between vehicles and infrastructure is expected to increase in the future. Hence, eCoMove requirements adhere to current European and national laws concerning data security, user anonymity and the protection of individual privacy: ECOM-RQ-IP-0034, ECOM-RQ-IP-0078.

On the core technology level, security requirements have been taken into account in the design of the eCoMove system to provide applications with a means to exchange data securely.

In a nutshell

1. Dynamic routing supported by ecoNavigation that respects the current status of the vehicle and includes traffic status information
2. On-trip driving assistance that provides recommendations to drive in the most fuel-efficient way by evaluating the driving style and traffic light status information
3. Post-trip analysis that helps the driver to improve

The main end users of eCoMove systems are the passenger car and truck drivers, the logistics planners, the road operators and traffic managers. Many more stakeholders can potentially be interested in eCoMove results, from the automotive and service provider industries to the research communities and public authorities.

Benefits for private car drivers

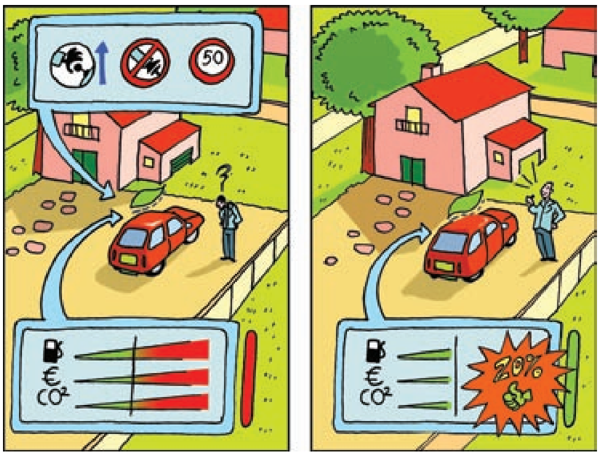
The eCoMove on-board system provides the first realisation of an ecoSmartDriving "virtual coach" that derives eco-information from different sources (maps, traffic data, road infrastructure, other vehicles) to provide the drivers with eco-related advice on how best to drive whilst adopting an eco-driving style.

The novelty of the ecoSmartDriving applications is that they operate in a network of information to improve the preview of the traffic situation ahead in order to determine the least fuel consuming route or way of driving. The driver receives from the infrastructure information about traffic problems to avoid, guidance on the most energy-efficient route and even smooth driving assistance to avoid stops at traffic signals.

eCoMove applications or services will result in positive effects on society, with direct effects such as lower fuel and time wasted.

Parts of this system are the ecoDrivingSupport and the ecoInformation applications that provide the driver with specific eco-recommendations. The HMI of the ecoDrivingSupport application is implemented as a visual display but also as an integrated force feedback accelerator pedal. With that, there is no need to observe the instruments and drivers can drive without potential distractions. Both applications influence driving behaviour and have been validated throughout a set of test drives. A statistically relevant fuel consumption decrease has been achieved.

HMI examples for the ecoDrivingSupport function



Another implementation of this system is the ecoPostTrip application that gives the driver an opportunity to look back and reflect on his/her own driving behaviour. Thus creating a perfect way to analyse and compare various parameters recorded during drives and provide additional information about drivers' eco-driving behaviour. For ecoNavigation, the driver receives relevant information to avoid traffic problems that results in guidance on the most energy-efficient route.

The ecoSmartDriving system demonstrated positive effects on the environment and driving behaviour. It has also been well accepted by drivers who tested the system in the different test sites and driving simulator studies.

Benefits for the automotive industry

The marketing for new vehicles now strongly features environmental benefits, specifically low CO_2 emissions and greater fuel economy. Indeed, given the global importance now of producing the “greenest” vehicles possible, the industry has every reason to look for new ways to save fuel and reduce their CO_2 emissions. However most “green” features are autonomous and eco-driving assistance is generally limited. By developing and proving a range of new concepts for eco-driving assistance, and for cooperative eco-traffic management, the deployment of the eCoMove project outcomes is expected to contribute to Europe’s industry in a leading position in the area of Intelligent Vehicle Systems.

The project approach is to bring together some of the most important stakeholders in Europe to collaborate on the definition of common principles, designs, specifications and standards. Each car manufacturer can then create its own technical solutions and products, knowing that they will meet customers’ requirements for effective and affordable features. Improved vehicle technology, however, cannot be left alone, and the eCoMove extensions to more fuel-efficient driving coupled with a more energy-efficient traffic management will be a key to meet the transport sector’s and the automotive industry’s targets.

Although any new feature tends to have a cost, in this case, the added value in terms of savings in fuel costs and CO_2 emissions is undeniable. The features might also qualify for subsidies or discounted taxes where these financial incentives are in place.

The driver consciousness about the cost and pollution reduction is fundamental to sustainably change driving habits. Consequently the ecoHMI will be the key factor to influence positively driving behaviour and this should be obtained by means of motivation, giving the driver a true understanding of efficient driving both in terms of economic savings and of environmental advantages. Drivers should be stimulated to compete with themselves and with the other drivers through a sort of playful contest for the best eco-driving performance.

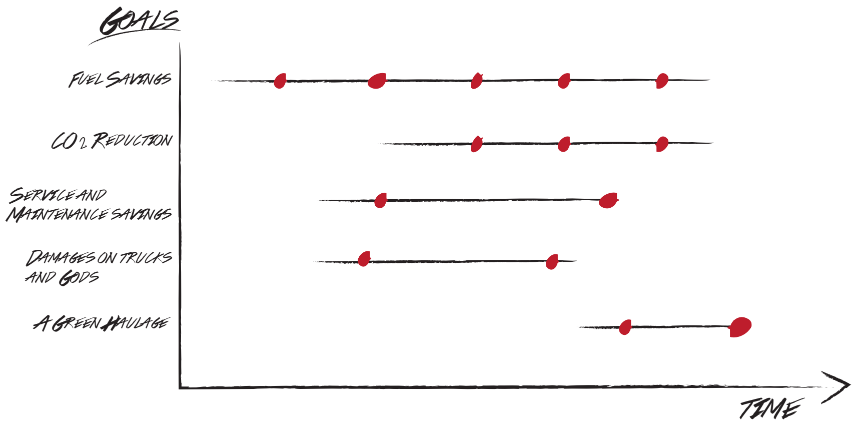
The experience and the results gained in the project will be a valuable input for the design of the new generations of in-vehicle information and telematics systems. The results of eCoMove are expected to have a positive impact on the future automotive products market penetration.

Benefits for logistics planners

The market for **freight & logistics** applications is to a large extent being driven by the interests of the private sector, i.e. maximise productivity and reduce operational costs. With this regard, reducing fuel consumption and useless kilometres driven have the utmost importance.

This can be influenced and optimised at different levels, starting by the dispatcher and how delivery missions are assigned to vehicles, to the best route choice depending on current situation, and finally to the driving performance of the truck driver. It can be implemented by a top down approach, from fleet & planning to the truck driver.

Within eCoMove, these different levels correspond to different levels of cooperation, both managerial and technical, with public authorities, traffic information, roadside units and local traffic lights and finally third-party vehicle data. The combination of truck specific-navigation and eco-navigation fits within the current demand from the fleet and transport domain stakeholders. The features might also qualify for subsidies or discounted taxes where these financial incentives are in place.



Tour optimisation and City Logistics access

The main aim of today's logistics companies is to perform transportation tasks with given assets in an efficient manner and in accordance with the promised service quality. IT-based tour planning assists the logistics planner during the dynamic planning and execution phase of the daily operation. During the planning phase, the **ecoTourPlanningSystem (ecoTPS)** supports the logistics planner with trip planning and optimisation functionalities. These algorithms plan and optimise transport orders, whilst respecting constraints and given restrictions. Furthermore, recommendations regarding the "right" vehicle for the mission can be advised.

Especially in urban environments, traffic congestion can have a severe impact on the daily operations of logistics fleets. An integration of traffic information into the planning and execution process provides an increase of planning reliability and reduces inefficiencies.

Finally the planning part also includes the calculation of energy consumption and greenhouse gas emissions of the planned trips according to EN 16258 "Methodology for calculation and declaration on energy consumptions and GHG emissions in transport services".

FUEL ADVICE

Before the execution phase starts, the ecoTPS has to announce the planned trips to the central City Logistics Service Centre to receive mission authorisation. Approved trips are then sent to the Truck ecoNavigation for execution during the mission. ecoTPS therefore enables the planner to keep track of the mission execution and to interact if needed.

City Logistics in eCoMove is a proof-of-concept ICT solution for the management of freight transport in urban areas based on (1) eco-sustainable criteria and (2) cooperation between firms and local authorities.

Eco-sustainable policy criteria considered within City Logistics are:

- reduction of the overall atmospheric pollution due to CO_2 emissions in urban areas
- overall vehicular traffic efficiency improvement
- overall urban logistics operational performance improvement

City Logistics is a collection of back-office functionalities operated by local authorities:

- "Policy Definition" used to define the policy parameters for freight transport and mission authorisation in the regulated city area
- "Missions Authorisation request" used by transport planners to request permission for a certain ecoTrip
- "Missions Authorisation" used to carry out authorisation processes in compliance with the considered policy

City Logistics requires the establishment by local authorities of regulation policies on freight transport (equivalent to the case of Limited Traffic Area for private transportation). Each ecoTrip goods distribution travelling towards the regulated urban areas must be authorised in advance by the local authorities, considering its compliance with policy criteria. ICT systems can support this process by providing relevant functionalities, information and data management. This approach is compliant with Freight Transport Logistics Action Plan – EC COM (2007) 607.

Truck ecoNavigation

The Truck ecoNavigation calculates the route to the next destination, as identified by its mission profile worked out by the ecoTour Planning application, and guides the driver to it. Truck-specific road attributes as well as additional constraints and requirements stemming from the fleet management are taken into account; the configuration and payload of the vehicle, as well as the traffic state information are considered, in order to determine the most efficient route in terms of travel time and fuel consumption.

The innovative aspects of the eCoMove Truck ecoNavigation compared to state-of-the-art systems are:

- Estimated fuel consumption derived from the evaluation with GPS probe data in conjunction with vehicle-specific fuel consumption models
- Consideration of road attributes such as slopes along each link
- Consideration of speed information received from the traffic management centre
- Consideration of energy consumption as obtained from learned consumption data
- Consideration of trip data from fleet planning

The route obtained thus provides a more realistic prediction of energy consumption for route alternatives, which enables users to make real energy cost savings and increases their willingness to choose the calculated ecoRoute for the trip.

Eco-driving

There are three key factors for sustainable fuel savings in a haulage company:
the human, managerial and technological factors.

True commitment by the management, clear communication and anchoring the key change factors are essential to achieving fuel savings in a haulage company

1 Human factors

The effects from eco-driving training are often short-lived. One reason is that information and knowledge are not always sufficient to affect people's behaviour and attitudes, which are central to achieve sustainable effects. People's motivation and intentions are key drivers in making the changes needed for sustainable fuel savings.

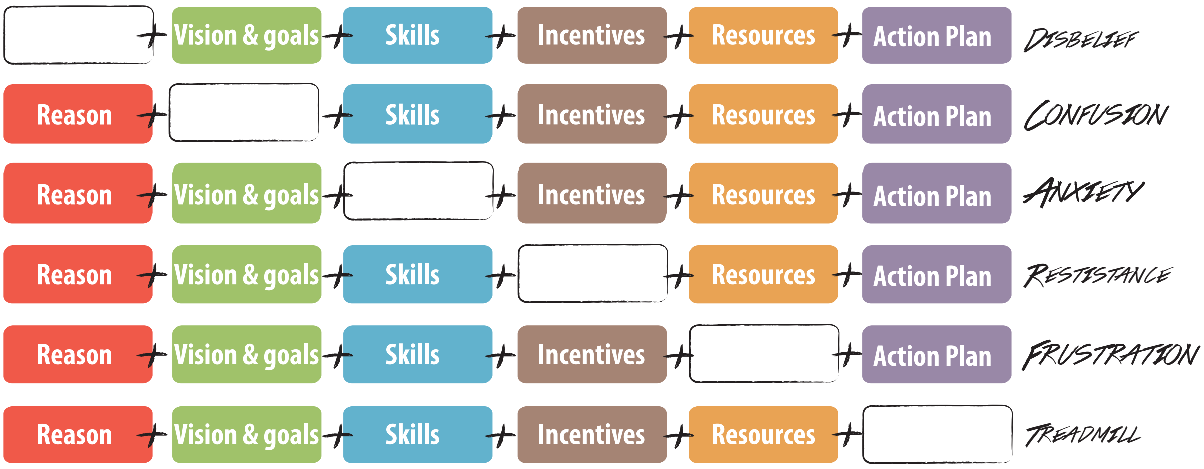
Successfully reducing the fuel consumption in a haulage company is dependent on peoples' physical, psychological and cognitive abilities to interact with technologies as well as with the organisational context.

2 Managerial factors

The management at a haulage company needs to consider the organisational changes required when initiating a plan to reduce the fuel consumption. The people in a haulage company have different roles, working tasks, responsibilities and ambitions. Therefore, it is important that some key factors are anchored in the organisation to achieve successful change:

- → knowing the **reasons** to save fuel, e.g. rising fuel costs or demands on decreased emissions
- → stating clear **goals** and formulating a **vision** – Why are we doing this and what do we want to achieve?
- → having **skills** and developing competences, e.g. training and education in eco-driving, in order to meet the challenges and tasks that the change requires
- → **incentives** making people motivated to contribute to the vision and goals
- → making the **investments** needed in e.g. technology, education, training, etc
- → having a clear and well defined process and **action plan** that guide all the people involved in the work towards sustainable fuel savings - Who does what and when?

Each of these key factors is important to succeed; if one (or more) are overlooked, there is a risk that different "symptoms" or undesired situations appear:

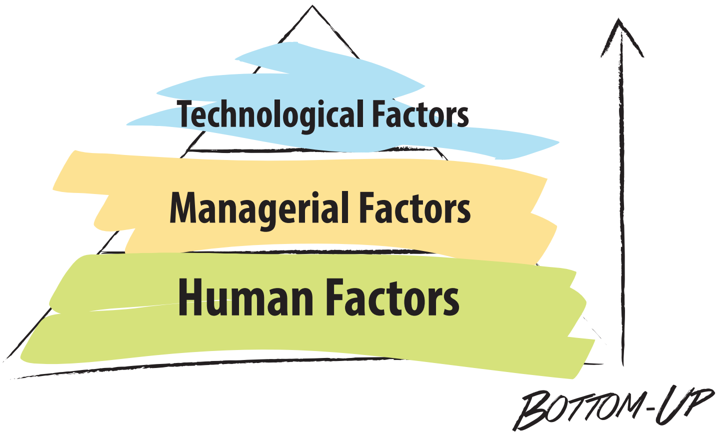


T. Knosler, 1991

This model can be used either to predict or to prevent the problems that organisations can face when working with changes.

3 Technological factors

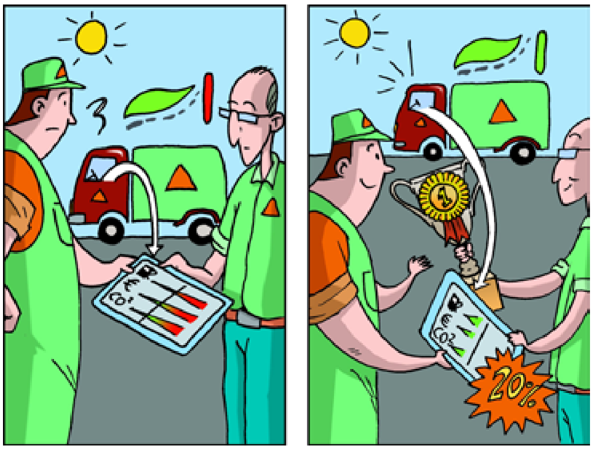
The third factor is about technology, e.g. technical systems that provide information to the driver on how to drive in a fuel-efficient way. It could also be technologies that log driving and fuel data over time, calculate, analyse and present the data for a manager to take strategic actions for further improvements.



It is essential to implement the technologies as integrated parts of the organisation, e.g. usage, follow-up, communication of data, etc, i.e. that the technology is part of the organisational context. If not, there is a risk that the technology will have limited and short term effects, e.g. on reducing the fuel consumption. So, to make the most out of the technology in a long term, it needs to be based on the human and managerial factors.

Within eCoMove, an eco-driving on-board application was developed and gives real time advice to the truck driver on three layers:

1. **Live vehicle data:** corrective advice e.g. after too hard accelerations, anticipation (time between acceleration and brake pedal switch) and wrong use of the retarder brake
2. **Static electronic horizon:** based on map data, anticipative advice encourages to coast before e.g. a speed limit decrease or use the retarder during hill driving
3. **Dynamic cooperative horizon:** based on V2X communication, the driver is advised about the best speed to approach equipped traffic lights



These three complementary layers construct an electronic view of the truck's live state and what lies ahead in the electronic horizon. Based on this, the coaching algorithm analyses the current and future situation to advise the driver on the best fuel-efficient way to handle his truck.

To effectively obtain sustainable fuel efficient driving, the truck driver can monitor his performance post-trip in the truck or on a back office application, with the possibility to compete in teams of drivers. The fleet manager has the complete view on his drivers and teams and can use this support tool to manage action plans and incentives programmes to sustain the positive effects.

Benefits for road operators & traffic managers

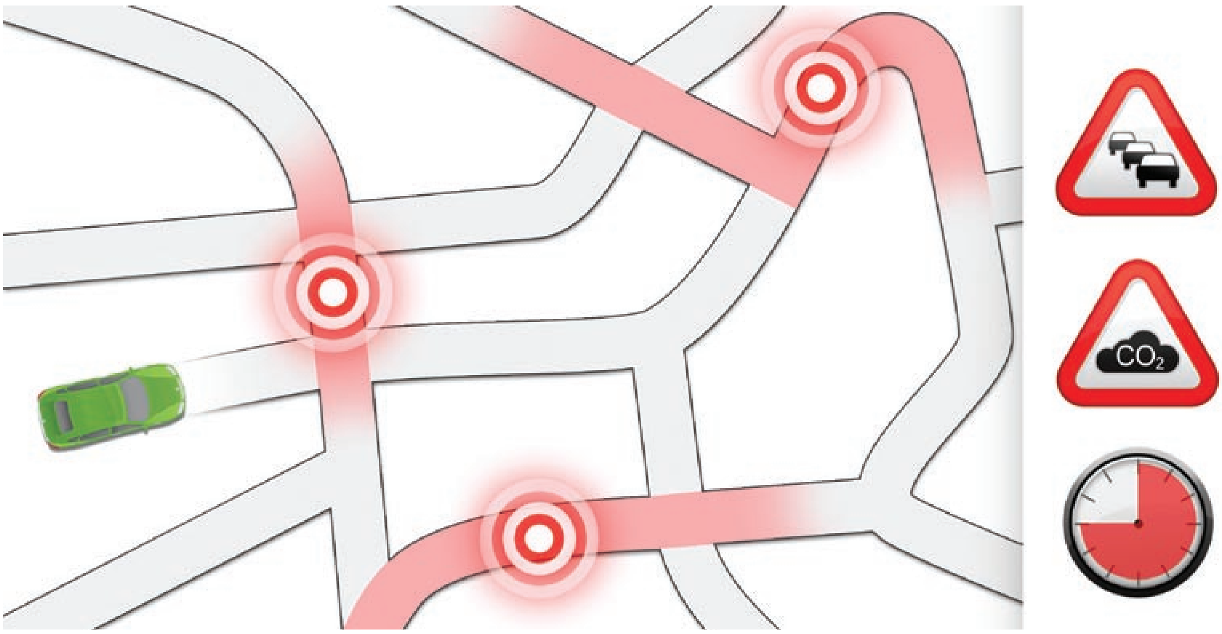
From the perspective of road operators and policy makers, cooperative traffic management and traffic control measures help them to achieve targets related to energy efficiency of road networks. Increased information available through vehicle-infrastructure communication improves the quality of state estimation models, the efficacy of management strategies, and the richness of information disseminated to vehicles.

eCoMove has taken a fresh look at traffic management and traffic control by optimising time efficiency and energy efficiency simultaneously, rather than primarily minimising delays as is the common practice today. Fortunately, evaluation results show that time efficiency and energy efficiency generally affect each other positively. Besides, interests of individual drivers can largely be preserved while improving the performance of the road network as a whole.

eCoMove has designed strategic and operational traffic management and traffic control applications and components, which function on all levels from network to area to local situations. Traffic states and emission models were developed to highlight bottlenecks and hotspots. Route and park advice applications were designed to evenly distribute the load of the road network. Speed and lane advice applications were developed to influence traffic flow dynamics. Traffic light control algorithms were improved to better facilitate traffic based on its volume and vehicle characteristics.

Building upon the latest standards in infrastructure-to-vehicle communication, the following information was transmitted to vehicles: traffic signal phase data, intersection topology, speed and lane advice, route advice, route diversions, traffic flow predictions and parking information. The largest benefits were found for applications which smooth vehicle trajectories by transmission of speed and lane advice to approaching vehicles. As a close second came the effect of route advice based on the calculation of the most energy efficient traffic distribution.

Finally, eCoMove examined what is a major challenge in traffic management and traffic control: interaction effects of application operation within the same domain, especially the combinations ecoGreen Wave - ecoApproach Advice and ecoRoute Advice. ecoBalanced Priority/ecoGreen Wave proved to have a larger impact than the sum of the effects of both applications alone. To provide a platform for applications to operate in a joint fashion, a system called ecoAdaptive Balancing & Control and a coordination scheme named ecoTraffic Strategies were designed. Both can help a breakthrough in the deployment of complex city-wide multi-objective traffic management.

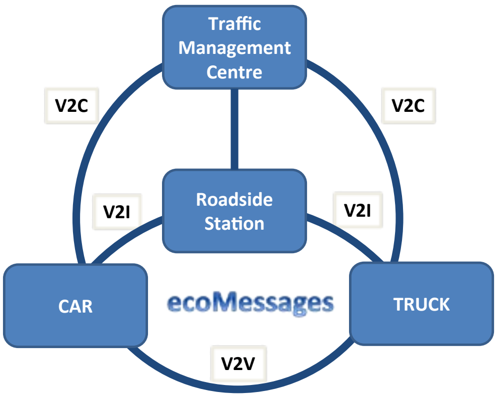


Technologies

The eCoMove project will develop an eco-cooperative system built around information exchanged via advanced V2V (vehicle-to-vehicle) and V2X (vehicle-to-infrastructure and vice versa) communication. Each eCoMove application is using cooperative data exchange either as originator or recipient.

In the system, an individual vehicle equipped with an on-board eco-driving system and communication platform can exchange data with infrastructure and other equipped vehicles. Likewise, an eCoMove roadside traffic management unit will be equipped with a fully compatible **communication platform** able to exchange data with equipped cars, trucks, etc.

This mutual data exchange is formalised in eCoMove by the definition of a number of **ecoMessages**, which have been designed to address the needs of the eCoMove applications. They cover a wide spectrum of use cases, from the vehicle-centric applications to the vehicle-to-infrastructure ones.



These ecoMessages will be sent over G5 (communications air interface ETSI G5 for medium range communications, harmonised with ISO CALM M5, WAVE and IEEE802.11p). The ITS communications architecture (ETSI EN 302 665), the standardised message for exchange of data between vehicles Cooperative Awareness Message or CAM (ETSI TS 102 637-2) and the standardised short-range event message Decentralised Environmental Notification Message or DENM (ETSI TS 102 637-3) are used as a basis for eCoMove core technologies and applications.

In this way, the project has been able to contribute both to assess these standards for eCoMove deployment and to provide feedback how these standards could be extended for environment-related purposes.
Certain data elements do not exist in current standards, e.g. truck load occupancy, fuel/energy consumption and power train type. To maintain compatibility with the current definition of CAM message, a new message has been defined: ecoCAM.

eCoMove communication platform

- **in-vehicle communication platforms** (or Vehicle ITS Station) located inside the vehicle and enabling communication with other vehicles, roadside units and central stations through various communication channels
- **roadside unit communication platforms (or Roadside ITS Station)** located inside roadside units and enabling communication with vehicles and central stations
- **eCoMove communication support centre** coordinating all communication from and to vehicles and roadside units

ecoMessage

Messages oriented to real time application

- **CAM:** Cooperative Awareness Message or CAM (ETSI TS 102 637-2, v1.2.1, 2011)
- **ecoCAM:** Supplementary information to CAM with information about fuel, engine, energy consumption and CO_2 emissions
- **ITM:** Infrastructure Topology Message describing road and intersection down to lane level. Also known as MAP and TOPO message (standardisation ongoing jointly in SAE and ISO)
- **SLAM:** Speed and Lane Advice Message containing driver advice for lane selection and optimal speed calculated by infrastructure elements
- SAM: Service Advertisement based in ISO and ETSI proposals
- **TSPDM:** Traffic Signal Phase Data Message containing information about current and future traffic signal information. Also known as SPAT message (standardisation ongoing jointly in SAE and ISO)
- **VPM:** Vehicle Path Message containing information about past driving history and possible future paths. Past driving history is now part of ETSI CAM message after alignment with BSM from SAE

Messages linked to traffic management and planning

- **TPEGM:** TPEG Message, a DENM-based container for sending TPEG over 802.11p using TEC (Traffic Event Compact), PKI (Parking Information), TFP (Traffic Flow Information) and RMR (Road and Multimodal Routes)

The eCoMove platform architecture implements the ITS Station architecture and is fully aligned with ISO 21217 and ETSI 302 665. eCoMove focus is on the Facilities and Applications Layer.

There are no security functions implemented in eCoMove. In addition, a common eCoMove execution platform was defined based on Java and OSGi.

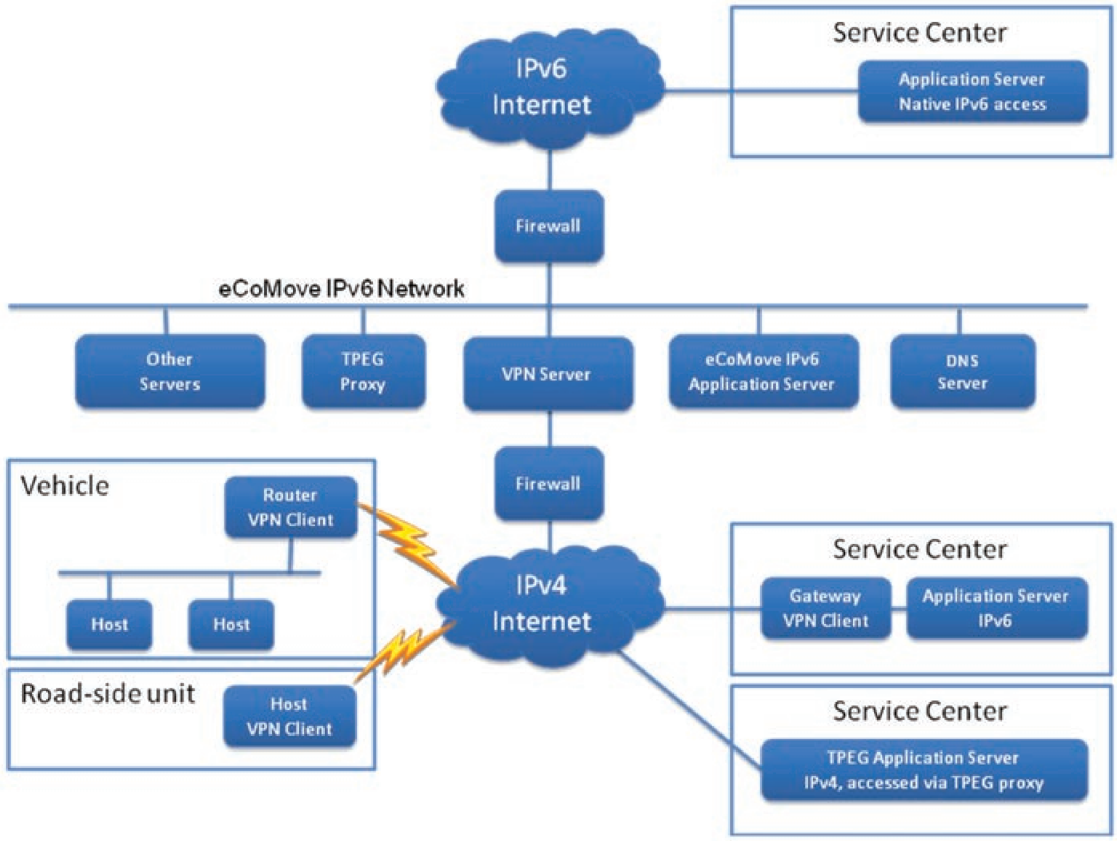
For successful interpretation of ITS messages, a common understanding of position and time is vital. The available standards relevant for the ITS Station Architecture and communication protocols did not properly define how to represent neither position nor time. The work of eCoMove partners on this topic has been successfully included into ETSI standards (CAM, DENM, Data Dictionary, Geonetworking), now in finalisation phase.

eCoMove communication platforms have been designed in order to allow interoperability among different implementations. The eCoMove team has conducted an in-depth study on the differences and commonalities of the different cooperative communication systems and concluded that the best approach to achieve interoperability is to define a communication profile that includes the most important features of existing communication systems.

eCoMove communication platform is open in the sense that the profile for the minimum level of interoperability does not specify any specific hardware and software, i.e. any system that is compliant with the profile will be interoperable with eCoMove.

Moreover eCoMove works with legacy systems and simulators that are operational, planned or available on the market. The implication is that the interface between legacy systems and eCoMove is system supplier-proprietary or country-specific.

The networking is based on IEEE 802.11p/ETSI ITS G5 and long range communication based on IPv6 over 3G. eCoMove provides a private IPv6 Network hosted in a Communication Support Centre. This enables end-to-end IPv6 connectivity by in-vehicle applications and back-end service centres. Current native IPv6 connectivity services offered by ISP and 3G networks are limited. The Communications Support Centre is able to completely mitigate this by offering IPv6 VPN service, transparent to applications. Furthermore, this offers network security advantages.



For successful interpretation of ITS messages, a common understanding of position and time is vital. The available standards relevant for the ITS Station Architecture and communication protocols did not properly define how to represent neither position nor time. The work of eCoMove partners on this topic has been successfully included into ETSI standards (CAM, DENM, Data Dictionary, Geonetworking), now in finalisation phase.

eCoMove communication platforms have been designed in order to allow interoperability among different implementations. The eCoMove team has conducted an in-depth study on the differences and commonalities of the different cooperative communication systems and concluded that the best approach to achieve interoperability is to define a communication profile that includes the most important features of existing communication systems.

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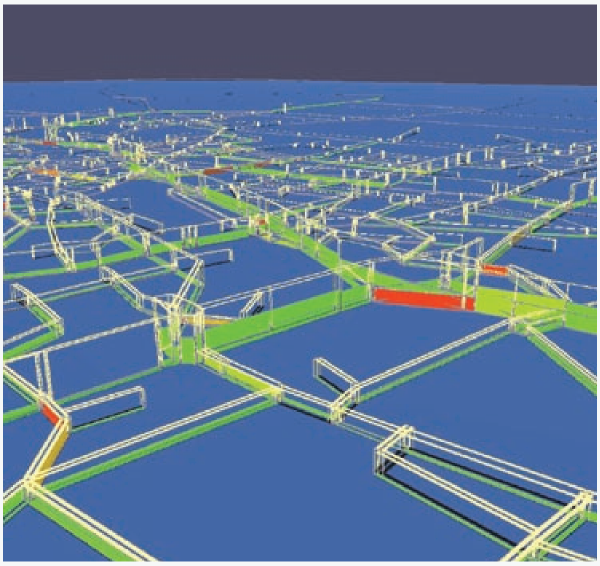


ecoMap

The general purpose of the ecoMap is to enable the eCoMove applications and models by providing and storing relevant static and dynamic spatial information. The ecoMap component has a core represented by traditional static navigation map data, extended with eco-attributes and historic behavioural information. The ecoMap is also a data container for dynamic information, both for traffic data and situational data.

ecoNavigation

Calculation of route under eco criteria which are based on static as well as dynamic properties of the road elements considered (ecoMap). The ecoNavigation provides the calculated route to the ecoCooperative Horizon to serve the "ecoAssist" eco-Driving support application.

ecoCooperative Horizon

In-vehicle component that determines the road segments in which the vehicle will probably drive into in the near future. It provides in-vehicle components with a logical view of the road ahead for the vehicle.

The ecoCooperative Horizon integrates the information from the static ecoMap, from the traffic centre, from other vehicles (both retrieved via the dynamic ecoMap), and from the dynamic ecoNavigation.

ecoSituational Model (eSiM)

The applications developed in eCoMove aiming to optimise efficiency are enabled by several supporting components. The prediction model "ecoSituational Model" (eSiM) is one of these enabling technologies as it predicts the behaviour of the driver in upcoming traffic situations and describes the current driving situation.

Details of the driving environment are modelled in the eSiM using static and dynamic data from the digital map along the current predicted route (the so-called Most Probable Path) for a horizon of about 2500 m.

Static environmental data including road classes, slope and curvature or changes in speed limits in the digital map are enhanced with dynamic traffic data. This contains the state of traffic lights and data of vehicles in the vicinity that provide their position, speed and direction via the digital map.

Other vehicles that are directly detected by radar sensors are also considered in the driving environment, as well as macroscopic data such as average velocities or traffic densities for a certain road segment.

In this virtual driving environment, a vehicle and a driver model are continuously simulated. The vehicle is represented by differential equations containing various parameters, e.g. total vehicle mass, drive train and aerodynamic resistances, in order to adapt the model to the specific vehicle characteristics. The driver model can be adjusted to different driver types by several parameters that represent the driver's preferences and recent driving behaviour.

The results of this microscopic simulation are sent to the ecoDriving Support application in form of a vector containing the predicted velocity of the vehicle and the distance ahead. Reliable predictions of future traffic situations and the driver's average behaviour in these situations are essential to derive well suited recommendations supporting drivers to reduce fuel consumption.

ecoStrategic Model (eStraM)

eStraM provides current and predicted information to the applications about the traffic and environmental state of the network. It also determines how much the situation can be improved by rerouting part of the traffic to more efficient routes. It is the basis for the eCoMove traffic management and control applications and it may also be used by in-vehicle and back office applications that need to know the current and expected state.

eStraM uses live traffic information to compute the current state of traffic in the network, and uses (the macroscopic version of) the ecoEmission Estimation component to add information about CO_2 emissions. A visualisation of the networks shows which links can be categorised as an emission hotspot.

In addition, eStraM also predicts what the traffic and environmental state will be 15 minutes ahead, using the current situation and historical data to make the predictions. By adjusting the cost function to make CO_2 emissions "more expensive", part of the traffic will be assigned different routes, which will result in lower overall emissions – the "desired state". More efficient routes can subsequently be communicated to drivers by applications such as ecoRoute Advice.

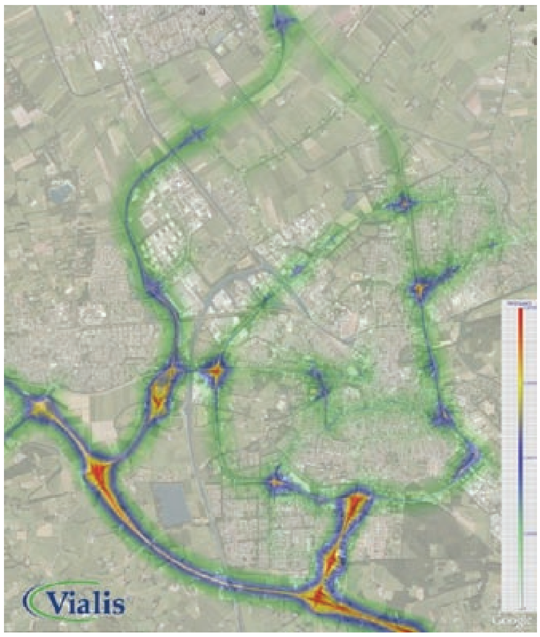
Hotspot situation in predicted and desired state plus percentage reduction of CO_2 emission

Calculating the emissions

If the aim of the eCoMove applications is to minimise fuel consumption and emissions, the applications need to be able to determine what actions will result in minimal emissions. The eCoMove applications are highly dynamic so a quick but accurate way of calculating emissions is needed. This is the role of the ecoEmission and Estimation component, which comes in two versions:

1. A microscopic variant that can be used with high resolution (1 Hz) speed and acceleration data, suitable for use in local applications such as ecoAdaptive Balancing and Control applications

2. A macroscopic version that can be used in network-wide calculations, using link and intersection data (e.g. type of intersection, traffic volumes)–this version was used in the ecoStrategic Model and ecoNetwork Prediction applications



Both versions of the ecoEmission Estimation component were based on TNO's detailed emission model VERSIT+ and its commercially available variant EnViVer (developed by TNO and marketed by Vialis and PTV). They have also been used in the validation and impact assessment.

Validation & impact assessment

The assessment of the impact of eco-friendly driving based on cooperative ITS solutions that optimise the network-wide traffic management & control, requires different methods to reveal effects and possible side effects.

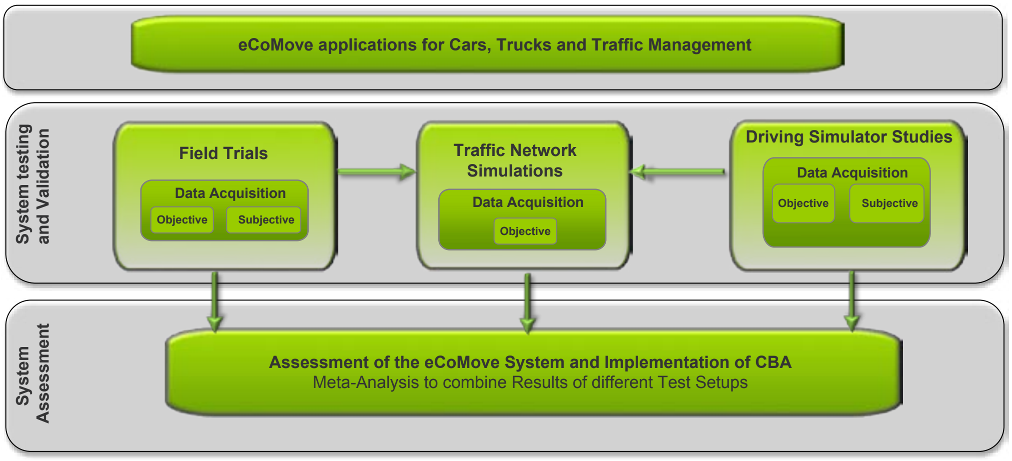
eCoMove deployment roadmap…

….including implementation strategies for the eCoMove concept and covering the following aspects:

- **requirements and barriers to implementation of eCoMove technologies**
- **cost-benefit analysis**
- **user acceptance study**
- **enablers and barriers to market take up and wide use of eCoMove applications for private and commercial vehicles**

Methodology

The eCoMove validation & evaluation approach is based on the FESTA methodology and adapted to the project specific needs and scope; it is composed of different methods:



[4] http://www.fot-net.eu/download/festa_handbook_rev4.pdf

Methodology

1 Questionnaire

Focus groups: private car drivers and truck drivers
Questions focused on the acceptance of technical systems (dependent on the perceived usefulness and ease of use as well as the behavioural intention and the attitude towards using the system)

2 Small scale field trials

The ITS tools developed within the project have been verified and validated on the field; however the number of equipped vehicles was very limited since eCoMove was not designed as a Field Operational Test and large scale testing was therefore not foreseen

3 Driving simulator studies

The ITS tools applied in the project are developed to support the driving performance with regard to an economic and environmental friendly behaviour with the aim to reduce emissions.

To reach this goal, it is important that the systems are accepted by the drivers and that drivers comply with the systems recommendations.

In order to gain a sufficient amount of high quality data for the impact assessment, different driving simulator studies have been conducted, in which the developed eco-driving support applications for private car drivers and eco coaching applications for trucks were validated.

4 Microscopic traffic network simulations

Not only were the field trials limited, but also most infrastructure applications refer to macroscopic aspects of road traffic and the impact evaluation of these applications requires a statistical analysis with a larger sample.

Microscopic traffic network simulation can substitute a large-scale Field Operational Test and reveals macroscopic effects of the potential system and technology. In addition, a micro-simulation can model the interaction of individual vehicles with traffic control.

The implemented microscopic traffic network simulation modelled the functionality of innovative applications rather realistically, including driver-vehicle interaction but also the interaction between eCoMove-equipped vehicles as well as between equipped and non-equipped vehicles. It allowed to determine vehicle-related effects (stops, delays, energy and emissions) on traffic management but also on combinations of eCoMove applications.

Course of action

Most of the tools developed in eCoMove to limit vehicle and traffic inefficiencies are only successful if the driver follows the recommendations. Therefore the designed validation and assessment methodology focuses on a variety of research questions and hypothesis which consider not only the single tool but also the overall system and especially the driver acceptance.

The velocity profiles including acceleration/deceleration, gear shifting behaviour and fuel consumption of the participants driving with and without the eCoMove systems were compared. Different scenarios (e.g. urban, rural, highway, traffic lights and curves) have been defined to realise a variety of driving situations but also different HMI designs and information strategies.

To evaluate the impacts in the different categories, a harmonised set of measures to be analysed is required, based on which indicators can be retrieved that ensure consistency between test methods when analysing available data.

Four impact categories to reflect the possible impacts of the applied cooperative ITS tools:

1. **Environment**
2. **Mobility**
3. **Safety**
4. **Acceptance**

Impact Category	Environment	Mobility	Safety	Acceptance
Performance Indicator	Fuel consumption of passenger car	Total travel time Number of stops	Critical time to collision, in seconds Standard deviation of speed, in km/h	Use of the system Ease of use Understanding of message

Example of impact categories and relevant performance indicators

Results of Studies

Participants in the field trials and driving simulator studies consisted of professional truck driver, company employees or random sampling of a volunteer pool.

A harmonised share between male and female took part in the study. Their aged ranged between 20 and 69 years.

For the evaluation of the system, a classical "Baseline versus Treatment-method" was applied. The range of CO_2 reductions over all studies found is between 4-25%. These results vary and are very dependant on the use case (urban vs. rural situations) but also on the (combination of) applications tested. Also, effects may vary locally i.e. at traffic lights.

CO_2 reduction between

4-25%

Impacts on Environment

Car Studies

Within the trials with private cars, a fuel reduction between 4.5% and 25.1% was identified. The fuel saving potential was higher on urban streets with many traffic lights compared to rural roads. Here, traffic situations with a very high fuel reduction potential are situations where to slow down because of speed limits, curves or stop signs.

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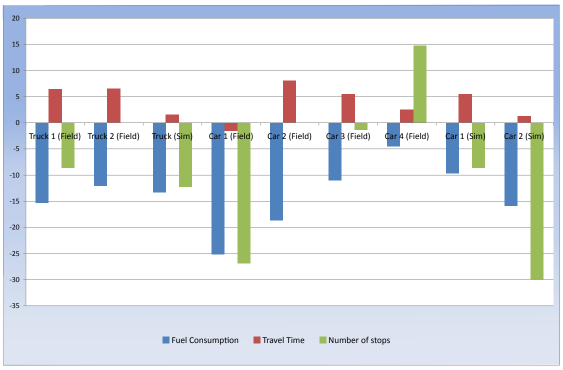
Truck Studies

The fuel savings are ranging from 2.4% to 15.3% within the driving simulator studies. On average 6% fuel savings could be realised by the truck drivers. The main reasons were the dependence on the road type but also on the loading of the vehicle. Both variables influence the fuel consumption to a great extent.

Impacts on Mobility

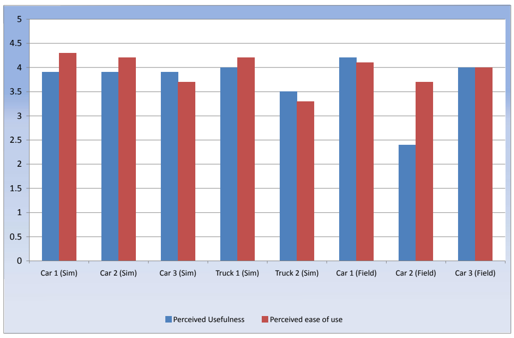
No significant difference between baseline and treatment for the performance indicators travel time, number of stops, etc, could be measured. At least within the truck simulator study, a slight increase in travel time at curvy and hilly roads could be identified with the assistant system. Hence, the number of stops decreased through the communication between vehicle and traffic signal.



Impacts on Acceptance

The acceptance of the experienced system was very high. The participants also assessed the system as very useful and effective. Most of the participants would like to use the eco-driving systems frequently.

Overall, the perception of the ease of use was rather high and the perceived usefulness of the driving support systems was also rather high in most of the studies. Still, most of the participants would not pay more money for the system than they could save through using it.



1= strongly disagree; 2 = disagree; 3 = neutral;
4 = agree; 5 = strongly agree

Impacts on Safety

None of the performance indicators with regards to safety showed that participants violated traffic safety. On the contrary, an increase of constant speed driving could be identified. A high reduction of time driven over speed limits and a larger safe distance could be measured. Also the driver compliance increased to about 70%.

Results show a reduction of fuel consumption by about 4.5-25% based on a more anticipative driving

Impacts on Driver Behaviour

The overall impacts of the eco-driving information showed a more anticipative driving style. A clear reduction of mean and standard deviation of the velocity could be observed. First, the driver behaviour changed to an earlier shifting and lower acceleration when using the system. Additionally, it could be observed that most drivers used more coasting strategies which resulted in increased engine brake and roll-out phases. Finally, the drivers showed a more harmonised driving style with less breakings and lower accelerator pedal positions.

No negative effects on traffic safety or on mobility could be observed

No negative effects on safety

Conclusion & next steps

eCoMove can reduce fuel consumption and therefore CO_2 emissions

eCoMove allows vehicles to know about downstream events and take action, e.g. to change route or adapt speed. Traffic control systems have more possibilities to sense approaching traffic and optimise their strategies based on this information. Infrastructure-to-Vehicle communication offers more flexibility to control traffic, e.g. more intersections become suitable for (two-way) green waves.

The extent of the effects depends on the traffic situation, the road network and the driver. Effects of driving support functions range between **4-25%**. Overall, results show that a reduction **> 10%** is feasible in urban networks.

The reduction realised by network and routing schemes depends on the traffic load of the network. If the network load is low or moderate, the reduction rate is expected to be rather small (around 4%). In heavily loaded networks, the reduction can be up to 12%. The largest impact can be achieved in case of severe incidents in the network, where it matters how fast road users can be informed about the incident and alternative routes.

Traffic light control should be as flexible as possible i.e. giving drivers a green light as quickly as possible to minimise delays. However, for energy efficiency applications (e.g. speed advisory) it is more efficient to switch to predictable traffic light control programmes. More research is thus needed to find the right balance between flexibility and predictability, i.e. between fuel consumption/emissions vs. travel time.

eCoMove is only about ITS for energy efficient traffic; it does not look at engine technology and it does not influence demand.

Indeed we could not cover in this project all situations in daily traffic. It is important to determine the impact of eCoMove on different networks, as well as to analyse the applications that give the best gain based on varying percentages of vehicles equipped with eCoMove. More tests in a naturalistic environment are also needed to assess the long term effects of eCoMove.

The logical next step would be to further test some applications in Field Operational Tests. Some applications may be ready for pilot tests. Besides, such tests can also be used to investigate drivers' compliance to advice under various conditions. Further tests will thus generate proof of the benefits (and costs) of the applications and will help to show how these applications help to make traffic and transport more sustainable.

Further research is needed to analyse whether some generic map attributes, e.g. standard deviation of speed or average acceleration/deceleration squared, are useful to estimate the average fuel consumption. Live average speed information is already available today, but neither the speed distribution nor smoothness.

Many drivers are unfamiliar with the type of support that eCoMove can provide, and as a consequence may not be ready to purchase the system. Marketing campaigns can help to make drivers (and other stakeholders, such as employers, transport firms, car dealers, policy makers) aware of the potential and ease of use of eCoMove functionalities.

Moreover, drivers' adoption depends on the system comfort of use and effectiveness:

- the system needs to be adaptive to the level of eco-driving skills the driver has (and develops over time);
- Drivers need step-by-step training to learn to work with the more complex systems in the vehicle, e.g. a haptic pedal. There also needs to be alignment between the eCoMove system and what eco-driving trainers teach;
- The system needs to motivate drivers by informing them of potential savings; the driver needs advice on how and when to act, but also on why an action is required; finally drivers need to get feedback about their improvements;
- Accuracy and reliability of the information needs to be high for drivers to trust the system;
- Establishing teams to make individuals feel engaged and committed to participate in a fuel saving programme, keeps commercial drivers motivated to use the system.

Deployment of intelligent transport tools such as those developed in eCoMove will not happen unless the industries involved collaborate to create solutions that are interoperable and harmonised. This is why eCoMove has been participating in international cooperation and standardisation efforts for elements such as vehicle-to-X communication means, message formats, contents and protocols, and core service definitions. These are absolutely necessary to ensure that any vehicle can exchange enhanced eCoMove data with any other vehicle on the road, and that any vehicle can access any service deployed anywhere in Europe.

Moreover eCoMove partners have been cooperating with related initiatives in Europe, US and Japan addressing cooperative systems standardisation, common definition of cooperative sustainability applications and the development of a common methodology to assess the impact of ITS applications on CO_2 emissions.

Finally the transport system is evolving towards automation. eCoMove solutions propose to help drivers to implement the best eco-strategy estimated for their vehicle in the current traffic network in order to become a perfect eco-driver. The logical next step would be to have this strategy not communicated to the driver but directly applied by the vehicle, e.g. with an eco-longitudinal control, leaving only the steering task to drivers, as long as their safety is ensured.

The usage of eCoMove solutions will rely on the deployment of Cooperative ITS in general, but will certainly provide traffic managers the additional means they need to best operate the traffic network within time and energy constraints.

Participants

The eCoMove project brings together a multi-disciplinary team to develop the necessary new tools to support energy-efficient driving based on cooperative traffic control and infrastructure.

Consortium:

Coordinator:

Facts & figures

eCoMove is a European Commission co-funded Integrated Project under the 7th RTD Framework Programme, Directorate General for Communications Networks Content & Technology (FP7-ICT-2009-4)

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EC Funding: €13.7 million

Cooperative Mobility Systems and Services for Energy Efficiency

Find out more

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