COOPERATIVE SYSTEMS AND SERVICES FOR ENERGY EFFICIENCY: FROM INEFFICIENCY TO EFFICIENCY

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ABSTRACT

The European Integrated Project eCoMove (EU FP7) aims to develop cooperative mobility systems and services that reduce fuel consumption and CO\textsubscript{2}-emissions with 20%.

The innovations that are developed inside the eCoMove project relate to driving behaviour, trip planning and traffic management & control.

As one of the first steps the inefficiencies that occur in the current system have been identified. Inefficiencies occur both pre-trip, when a trip is being planned as well as on-trip, when the vehicles are driving in the road network.

Pre-trip inefficiencies that are target by the eCoMove project are related to:

- Vehicle condition: e.g. low tire pressure, heavy (unnecessary) loading, tire condition, vehicle maintenance condition;
- Trip planning: e.g. route choice, travel timing, payload (truck-specific).

On-trip inefficiencies targeted by eCoMove are related to:

- Secondary (driving) tasks:
  - Vehicle condition & energy consumers: e.g. driving with open windows, using A/C, heaters, other energy consumers;
  - Inefficient routing: e.g. driving around looking for a parking place, no adjustment of route to traffic situation / road side signals, inefficient lane choice (e.g. causing late merging).
  - Primary driving tasks: e.g. acceleration / deceleration, gear choice, idling, speed, stops.

Each of the use cases and resulting components and applications that are developed in the eCoMove project, targets one or more of the above mentioned inefficiencies. In this way the inefficiencies are used to keep a clear focus on the project goal of reducing CO\textsubscript{2}-emissions and unnecessary fuel consumption with 20%.

INTRODUCTION

The concept behind the eCoMove project is that, for a 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 (see Figure 1). In the current situation, both drivers and traffic management system fall short of this ideal, and much energy is wasted and CO\textsubscript{2} emitted unnecessarily.
Wasted energy due to:
- Inefficient deceleration
- Wrong gear & engine speed
- Excessive speed, acceleration
- Poor anticipation
- Congestion
- Poorly synchronised signals
- Choice of inefficient route
- Lack of know-how, motivation

Energy consumption of "perfect eco-driver"

ecoSmartDriving
ecoTrafficManagement + Control
ecoFreight & Logistics
Residual wasted energy

Energy consumption of "perfect eco-driver"

Figure 1: The eCoMove vision

PROJECT OVERVIEW

The eCoMove project is split up into six numbered subprojects (called SP’s) and structured according to Figure 2. The systems and applications are developed in the subprojects ecoSmart Driving (SP3), ecoFreight & Logistics (SP4) and ecoTraffic Management & Control (SP5) and integrated in subproject Core Technology & Integration (SP2). Subproject Validation & Evaluation (SP6) focuses, as the name suggests, on the validation and evaluation of the eCoMove systems.

The work in eCoMove is structured according to the V-Model, also depicted in Figure 2. This paper describes part of the work that has been done in the Work Package 2 phase of the project, that aimed to define the user needs, use cases and requirements that form the basis for the development of the applications. To define these aspects it is important to know where unnecessary fuel consumption is caused (the inefficiencies) and how they can be targeted. These inefficiencies are topic of this paper.

Figure 2: eCoMove Subproject and V-Model Process Structure
THE ECOMOVE CONCEPT

The eCoMove project aims to target this unnecessary fuel consumption without impairing the quality of mobility of people and goods by using information and communication technologies (ICT) to realise a cooperative system that enables improved energy efficiency. Wasted energy caused by inefficient driving behaviour can be addressed by eco driving systems including pre-trip planning, real-time cooperative eco-driving support and post-trip feedback. Wasted energy due to inefficient traffic management can be addressed by eco-traffic management including Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) information exchange. In this context “eco” means a specific variant of an ITS measure that is specially configured to improve energy efficiency.

The applications developed in the eCoMove project can support the driver and the traffic management by exchanging data that describes the current state of both the vehicle (and the way the driver is driving in the vehicle) and the traffic situation. This data comes together in the ecoCooperativeHorizon that is used to predict the near future ahead of a vehicle or around a Road Side Unit. This prediction can be used to optimise traffic signals and individual driving strategies for vehicles.

Using the eCoMove applications both the driver as well as the traffic management center can improve their performance and reduce the energy consumption. The eCoMove operation environment, including high level entities involved in the eCoMove System plus an example of specific data objects and applications related to a selection of use case scenarios, is shown in Figure 3.

![Figure 3: Overall system concept](image)

All entities displayed in Figure 3 are employed to realise the eCoMove subproject objectives, and are specified in (1), (2), (3) and (4).
TRIP PHASING

A division into three trip phases is relevant for the eCoMove project. These phases are in the first place used for the identification of the inefficiencies that occur in the current system. Later in the project they are used for the design of the architecture and the development of the applications that target these inefficiencies. The phases are defined based on the driver action state and can be described as follows (see also Figure 4):

- **Pre-trip phase - Planning**: in this phase the driver creates travel plans (in case of a fleet operators it could also be the fleet planner). Planning as such does not directly impact fuel consumption or CO2-emissions. However, decisions made in this phase can influence the actual execution of the trip. This phase starts when the driver plans his / her trip and checks the vehicle. The driver can do this either in the vehicle or at home / office / etc.. It ends with the driver starting his / her vehicle to drive to the planned destination;

- **On-trip phase - Acting**: in this phase the driver drives the vehicle within a network that is controlled by the traffic management centre. Here the driver’s choices and actions directly affect energy consumption (such as driving behaviour, destination changes, etc). This phase starts with the moment the driver starts the vehicle to drive to the planned destination. The phase ends with driver switching the engine and ignition off and trip-destination had been reached.

- **Post-trip phase - Analysing**: in this phase the driver analysis his / her driving behaviour, receives feedback and learns how his / her driving behaviour and route choices have

![Figure 4: Trip phasing in eCoMove](image-url)
impacted the fuel consumption and what possibilities he / she has to improve this in the future. Therefore this phase indirectly affects energy consumption.

INEFFICIENCIES ANALYSIS

Inefficiencies occur both pre-trip, when a trip is being planned as well as on-trip, when the vehicles are driving in the road network. Inefficiencies cannot occur in the post trip phase, since this is 'only' an analysis phase where the actions of the pre-trip and on-trip phase are analysed for their improvement potential for future trips.

Pre-trip inefficiencies that are target by the eCoMove project are related to (pictures show some illustrative examples or scenarios):

- INEF01: Inefficient vehicle condition; this inefficiency can be split into:
  - Conditions that can be measured / recognised by systems in the vehicle, like tire pressure and maintenance status;
  - Conditions that cannot be measured / recognised by the vehicle like unnecessary weight in the vehicle, carriers that influence aerodynamics, tire condition.

- INEF02: Inefficient route choice; when planning a trip the driver can already select a certain route which is not necessarily the best one from fuel consumption perspective. Reasons for an inefficient route choice could be lack of knowledge on traffic state on selected route, insufficient knowledge about route-alternatives, or insufficient knowledge about factors influencing fuel consumption on the route.

- INEF03: Inefficient travel timing; not only the route as such but also the time a trip should take place (or the chosen start / targeted arrival time) can impact the fuel consumption due to e.g. heavy traffic that causes congestions and therefore inefficient driving. Travel timing is chosen before the trip and if it is possible to adjust the timing to e.g. traffic conditions the trip could be covered with less fuel.
• INEF04: Inefficient payload; Maximising the payload (on volume or weight) of his vehicles is one of the main objectives of the transport planner. Thereby a high payload does not necessarily mean high efficiency. Only the use of the right vehicle under the right conditions with an optimum payload leads to high efficiency. Finding this ideal combination will be the main objective for the ecoTour Planning system.

Nevertheless it can happen that no transport orders are available and the truck is driving half-loaded or even empty. This may lead to the situation that one or more half-loaded trucks are driving through a city or on a highway. This is of course from traffic and safety point of view not desirable. Several ideas exist to solve this issue (e.g. centralised transport planning or warehouses at city limits). Often they infringe with economic principles and could even endanger market mechanism. Instead of regulations only addressing the actual payload, cities should think about policies and incentives that address the inefficiency itself. Therewith they could force carriers to corporate themselves to be more efficient.

On-trip inefficiencies targeted by eCoMove are related to:
• Secondary (driving) tasks:
  • INEF05: inefficient use of (electrical) energy consumers: many drivers are not aware of the additional fuel that is consumed when many auxiliaries are used when driving a vehicle. Electrical energy consumption has a direct effect on fuel consumption of a vehicle.
  • INEF06: inefficient on-trip vehicle condition: this inefficiency is similar to INEF01, but in the case the driver is already driving. Examples of relevant inefficiencies are driving with open windows or reduced tire pressure during the drive
  • INEF07: inefficient routing. During the trip the driver has to find his/her way to the destination, with or without using a navigation system. In addition to the route choice itself several other routing inefficiencies can occur that are relevant for ecoSmartDriving. These can be both on a macro scale when e.g. there is a traffic jam, or finding a parking place, but also on a micro scale, taking the wrong lane for a fluent traffic flow.

• Primary driving tasks: the inefficiencies that are included in this category relate to the longitudinal control of the vehicle by the driver – everything he/she does to achieve,
maintain or reduce speed, including gear shift. For each of the inefficiencies, reasons that cause these inefficiencies are listed: they can be traffic induced, road induced, weather/environment induced, driver induced, traffic signal induced or vehicle induced:

- **INEF08**: inefficient acceleration – e.g. too strong or too slow acceleration (depending on vehicle / situation), over-acceleration.

- **INEF09**: inefficient deceleration – e.g. approaching a situation with too high speed.

- **INEF10**: inefficient (unnecessary) idling – e.g. not turning the engine off when waiting at a railway crossing or traffic light.
- **INEF11**: inefficient speed – e.g. strong variation of speed between traffic calming measures, wrong speed for green wave.
- **INEF12**: inefficient gear/rpm – e.g. driving in a too low gear for the situation / speed.
- **INEF13**: unnecessary stops – e.g. stops caused by traffic lights that are not synchronised.

INEF13 is only relevant for Traffic Management & Control since the inefficiencies included here are caused by and can only by solved by this subproject. For more details please look into (4).
For each of the application sub project the inefficiencies have been prioritised to and use cases and applications have been defined that target to reduce the inefficiencies.

**ECOMOVE APPLICATIONS**

The applications that have been defined in the eCoMove project can be subdivided into the following categories (which are also represented in the project structure as application sub projects):

- Passenger cars;
- Freight and Logistics; and
- Traffic management and control.

**PASSENGER CARS (SP3)**

For passenger cars this means that the eCoMove project develops applications for a given trip and a given vehicle and therefore the applications do not aim to influence the trip choice as such (except from proposing a more advantageous start time) or the selected vehicle or transport mode. The focus of the applications that will be developed for passenger cars is on how a given trip in a given vehicle can be made with the least amount of fuel.

The following applications will be developed:

- ecoTripPlanning: help the driver to plan his trip better by e.g. providing a route with least fuel consumption and supporting him to find the best travel time;
- ecoSmartDriving:
  - ecoNavigation: guide the driver along the most efficient route;
  - ecoDrivingSupport: provide real-time recommendations to the driver to enable driving as fuel efficient as possible;
  - ecoInformation: provide information to the driver on the impact of vehicle settings to the fuel consumption;
- ecoPostTrip: provide feedback to the driver, once the destination has been reached, on how well (or bad) he has been driving and where the driver can improve him/herself.

These applications are supported by the ecoMonitoring application that provides relevant vehicle data to other vehicles and infrastructure units.

**FREIGHT AND LOGISTICS (SP4)**

For freight / logistics the eCoMove perspective does not question the requested goods transport as such, but aims to optimise the way this transport is organised from planning stage to the way the driver is driving. This means that for example a different trailer-truck combination, a different loading or an alternative route can be proposed, as well as on-trip driver coaching to reduce fuel once the route has been determined.

The applications foreseen in this area are:
• ecoDriver Coaching System: supporting the driver to drive in the most fuel efficient way;
• Truck ecoNavigation: calculating the most efficient route to the next destination and guiding the driver along that route;
• ecoTourPlanning: allowing the transport planner to determine the most fuel efficient daily (or weekly) ecoTours of all his vehicles based on a given set of transport orders.

TRAFFIC MANAGEMENT AND CONTROL (SP5)
The ecoTraffic Management and Control measures that will be developed within eCoMove are based on the assumption of fixed traffic demand including the time of travel. Therefore topics like demand management, road pricing and multi-modal travelling are out of the scope of this project. Clearly less vehicles means less fuel consumption, but the primary aim of the ecoTraffic Management and Control subproject is to reduce fuel consumption based on the current traffic situation.

Three systems which overlap each other but define three major targets in the traffic management domain of eCoMove have been defined: ecoAdaptive Balancing and Control ("ecoABC"), ecoMotorway Management ("ecoMM"), and ecoAdaptive Traveller Support ("ecoATS").

The objective of ecoABC is to balance traffic demand and network capacity at strategic (network), tactical (area) and operational (local) levels by combining vehicle generated data and road-side sensor data. It addresses the paradigm of travel time versus CO\textsubscript{2}, with consideration of traffic safety, comfort, reliability and other pollutions.

The objective of the ecoMM system is to reduce fuel consumption and CO\textsubscript{2} emissions by smooth traffic control in motorways systems; it combines energy-optimised speed and flow management measures with tools to improve metering and merging assistance at individual vehicle level. This system coordinates measures that are implemented on a motorway system. It contains a monitoring and state estimation and prediction component, as well as emission estimation and prediction.

The objective of ecoATS is to improve traveller information to enable new or improve existing applications supporting the driver or driver assistance systems. It addresses the paradigm of lack of information which is often a drawback for applications as routing and navigation, smart driver assistance as green wave assistance systems.

All three of these SP5 systems consist of a collaboration between the following SP5 applications: ecoGreen Wave, ecoBalanced Priority, ecoRoute Advice, ecoRamp Metering and Merging, ecoSpeed and Headway Management, ecoTruck Parking and ecoTolling.
For more details on these applications, please check (4).
FROM INEFFICIENCY TO EFFICIENCY

Now the inefficiencies and the applications have been described it is possible to show with an example how the process inside the eCoMove project has been performed to come from inefficiencies to efficiencies.

With the inefficiencies as a starting point it is well defined what type of situations are relevant for the development of use cases. For example: the inefficiency INEF09 (inefficient deceleration) focuses on all these situations in the traffic where drivers tend to decelerate using brakes.

<table>
<thead>
<tr>
<th>Use Cases</th>
<th>UC No. (UC_xx)</th>
<th>Applications</th>
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<tbody>
<tr>
<td>SP3 ecoSmartDriving Use Cases &amp; Applications</td>
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<tr>
<td>Support ecoDriving</td>
<td>SP3_06</td>
<td>ecoDrivingSupport</td>
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<tr>
<td>In-Vehicle ecoTripFeedback</td>
<td>SP3_07</td>
<td>ecoPostTrip</td>
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<td>Off-Board ecoTripFeedback</td>
<td>SP3_08</td>
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<tr>
<td>SP4 ecoFreight &amp; Logistics Use Cases &amp; Applications</td>
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<tr>
<td>Support ecoDriving</td>
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<td>ecoDriverCoaching System</td>
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<td>Driver evaluation</td>
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<td>SP5 ecoTrafficManagement &amp; Control Use Cases &amp; Applications</td>
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<td>Coordinate traffic controllers</td>
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<tr>
<td>Support merging</td>
<td>SP5_05</td>
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<tr>
<td>Improve intersection control</td>
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<tr>
<td>Balance intersection control objectives</td>
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<td>X X</td>
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<tr>
<td>Improve ramp control</td>
<td>SP5_08</td>
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<tr>
<td>Improve lane usage</td>
<td>SP5_09</td>
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<tr>
<td>Improve approach velocity</td>
<td>SP5_10</td>
<td>X X X</td>
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<tr>
<td>Improve traffic flow stability</td>
<td>SP5_11</td>
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</table>
The most efficient deceleration strategy depends strongly on the situation and type of vehicle, but it is obvious that usage of brakes to decelerate is always a loss of energy. Each of the application sub projects targets this inefficiency with at least one use case and as a next step at least one application (see Table 1).

For the Passenger cars and Trucks the approach is very similar: supporting the driver to start decelerating as earlier as possible, if there are known causes for deceleration ahead of the vehicle (e.g. red traffic light, sharp curve, traffic jam, lower speed limit). From the Traffic Management & Control side this inefficiency is targeted in two ways: first trying to avoid a deceleration by optimising traffic signal settings that avoid unnecessary speed, second supporting the vehicles with information they can use to know in advance when they have to slow down. As can be seen in Table 1 these aspects are covered in several use cases and several applications inside the ecoTrafficManagement & Control subproject.

**OUTLOOK**

The approach described above has been applied throughout the whole eCoMove project and the usage of the inefficiencies also helps to keep the focus on what a defined application is targeting.

In the next phases of the eCoMove project the applications will be further developed and demonstrator vehicles and sites will be build up to show that what eCoMove is targeting can really be realised in the future: a cooperative system that enables much better energy efficiency and is able to reduce road traffic CO$_2$-emissions by 20%.

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