eCoMove: integration of results and conclusions

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Abstract

The eCoMove project developed and analysed several applications aiming to improve fuel economy and reduce emissions. V2X communication is used to connect traffic management and road side units with vehicles and enables information exchange between all participants. The research questions of the project focused on the reduction of fuel consumption, the change of driver behaviour and the impact of the applications on the traffic system. This paper summarizes the main findings of the project and elaborates on the three high level research questions in more detail.

Keywords: Road traffic, Cooperative ITS, fuel consumption, CO_2 emission, eCoMove

Introduction

The eCoMove project set out to develop, test and validate several core technologies, components and applications [1]. The aim was to reduce the fuel consumption (and CO_2 emissions) by 20 %, by helping drivers to apply the appropriate actions and driving strategy, by determining and advising the most efficient routes and route planning, and by applying the most efficient traffic management and control measures. The eCoMove system uses V2V and V2I communication to enable new kinds of interaction between vehicles, and between vehicles and infrastructure. The main idea is illustrated in Figure 1, which shows a wide range of inefficiencies that the eCoMove system targets in order to reduce energy consumption.

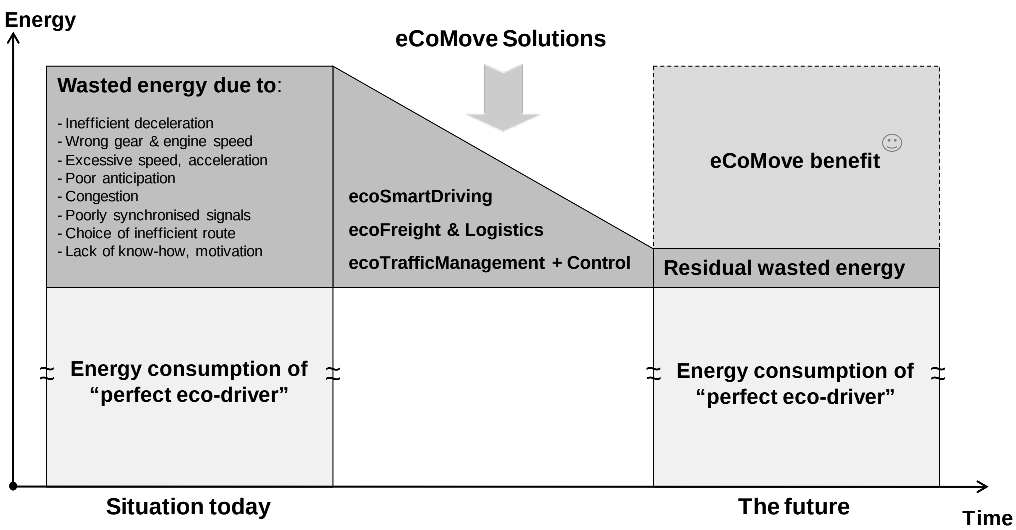

Figure 1: The eCoMove vision

At the start of the project, the following high-level research questions were formulated:

- To what extent can eCoMove decrease the fuel consumption and therefore also CO_2 emissions with cooperative technologies?
- How can eCoMove sustainably change the behaviour of private and professional drivers into a more eco-friendly driving style?
- What impacts do eCoMove solutions have in a cooperative environment for the traffic system?

These are the questions that we seek to answer in this paper. In addition a number of research challenges formulated at the beginning of the project will be addressed. This gives a convenient summary of the eCoMove results. The content of this paper has been taken from eCoMove-deliverable D6.5 [2].

Conclusions with respect to the high level research questions

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

The eCoMove validation and evaluation results indicate the following:

- The systems developed in eCoMove can reduce the fuel consumption and therefore CO_2 emission.
- The extent of the effects depends on the traffic situation, the road network, and the driver. Effects of driving support functions (tested in the field and in driving simulator studies) range between 4-25 %. See deliverables 630.63 and 640.64 for an overview of all results.
- There is quite some variety in the size of effects found for the traffic control applications that were evaluated using microscopic traffic and emissions simulations. They are heavily influenced by the conditions under which the applications were tested, and the reference situation (the “without eCoMove” situation). Benefits found ranged between 0.8 and 11.9 % (for all traffic; effects for individual vehicles can be higher). There were also a few situations where the emissions increased slighted (a few percent), because the application turned out not to be suitable for the specific situation (e.g. because a generic speed advice for all vehicles does not necessarily result in lower emissions). On average, an overall effect of 4-5% seems feasible, but a larger effect may be reached with carefully selected and tuned applications. Not much improvement can be achieved in oversaturated situations.
  - Larger effects were found when the application was implemented on a site with less advanced existing control systems. For example, fixed time / pre-timed traffic control instead of vehicle actuated control.
  - Furthermore, effects were larger in tests where the reference situation had a large potential for improvement, because of favourable intersection topology and/or a favourable distribution of traffic over the turning directions.
- There is a potential in fuel savings due to route planning and route advice application which can result in extra travel time (10 % for the overall network and up to 20 % for the individual –equipped– vehicle). Results depend on alternative routes being available, the network typology and the traffic load.
- Routing and driving support functions are expected to add to each other in most cases *(if they were to be used in combination on any given trip).*

In the eCoMove project, the target was a 20 % reduction of fuel consumption and CO_2 emissions. The question is: **Will we reach a 20 % reduction of fuel consumption / CO_2 emissions (overall)?** From the project results, the following conclusions can be drawn:

- The eCoMove system is efficient (to the point where a 20% reduction can be reached) in the situations where it provides support.
- It is, however, not known how many of these situations are going to be active on any given trip:
  - It was not possible to determine the overall reduction from our test setups – we could not cover all situations in daily traffic in this project, and there were too many unknowns to make assumptions about situations not covered.
  - The eCoMove system, nonetheless, covers several use cases and deals with many inefficiencies, for instance the vehicle condition (pre-trip and on-trip), inefficient routing and inefficient driving (either due to the road geometry, the surrounding traffic or traffic signal settings). The complete sets of use cases and inefficiencies have been reported in [3]; use cases and inefficiencies targeted by the eCoMove system are included in this deliverable in appendix B.
- *Overall, then, a 20 % reduction seems too ambitious, but results show that a reduction of more than 10 % is feasible in urban networks.*

There are other options for reducing fuel consumption and CO_2 emissions than the cooperative ITS developed in eCoMove. The following needs to be taken into account when looking at the eCoMove results:

- The project did not look at engine technology.
- The project did not look at influencing demand, e.g. through road charging, mode shifts → eCoMove is only about ITS for energy efficient traffic.
- The project did not look at advices regarding energy-efficient speeds in free flow traffic on motorways, e.g. at lower speeds than the speed limit.

Research question 2: ***How can eCoMove sustainably change the behaviour of private and professional drivers into a more eco-friendly driving style?***

For the system to be the most comfortable to use and the most effective, the following is recommended:

- 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. with a haptic pedal.
- The system needs to inform drivers about potential savings so he/she is motivated.
- The driver needs to get feedback about his/her improvements.
- Accuracy and reliability of information & advice needs to be high for the driver to trust the system.
- To keep commercial (and private) drivers using the system it is important to communicate clear short and long term incentives to use the system.
- Legislation/regulation with regard to privacy, security, reliability and safety needs to be addressed within the context of cooperative systems.
- To achieve higher effects, (partial) automation of the driving task can be considered as a next step.
- More tests in a naturalistic environment are needed to assess the long term effects of eCoMove.

- There needs to be alignment between the functionalities of the eCoMove system and what eco-driving trainers teach.

Research question 3: ***What impacts do eCoMove solutions have in a cooperative environment for the traffic system?***

The results of the eCoMove project show the following benefits from the cooperative environment in which the applications work:

- eCoMove allows vehicles to know about downstream events, and take action, e.g. to change routes or to adapt speeds.
- Traffic control systems have more possibilities to sense approaching traffic and optimise their strategies based on this information.
- It is possible to optimise the system (all traffic), rather than only optimise the trips of equipped vehicles. Predictability for users in vehicles is important in the optimisation.
- I2V communication on intersections offers more flexibility to control traffic. For instance, more strings of intersections become suitable for (two-way) green waves.

The following aspects need more attention: the traffic lights change their advice to vehicles too often, which requires constant adaptation from the drivers (which is uncomfortable). Bilateral negotiations could be useful. More research is needed to find the right balance between flexibility and predictability, and to find the desired balance between policy objectives.

Conclusions with respect to the research challenges

Research challenge 1: ***What are the most important factors of driver action and vehicle control that influence instantaneous fuel consumption, and how can they be integrated into a model that provides real-time advice to help a driver to “eco-drive”?***

The most important factors are gear shifting, acceleration (and anticipating deceleration, e.g. coasting) and choice of velocity (for instantaneous fuel consumption). With the eHorizon, the driver has information to better anticipate many events. Choosing an efficient route is an important factor on another level (not instantaneous). Additional factors are climate control / air conditioning, tyre pressure, ski boxes, trailers, the load. eCoMove has pre-trip and on-trip applications that deal with all of the above issues.

Research challenge 2: ***What additional map attributes and content are needed so that a driver can be guided along the most energy-efficient route to his destination?***

Energy-efficient guidance does not need to be different from a standard navigation system once a route has been selected. But additional data are needed to optimise a route for fuel efficiency:

- Static attributes used in driver coaching, such as slopes, curvatures, static speed limits, traffic signs (stops, roundabouts).
- Dynamic attributes such as traffic light status, traffic densities and speeds, vehicle speed, position, heading, etc. (for ego vehicle and other vehicles nearby). Also, information on the homogeneity of the traffic flows, or, viewed from the other side, on acceleration/deceleration behaviour of vehicles. For fuel consumption, there is a large difference between smooth traffic and stop-and-go traffic even with the same average velocity. Current maps only include average speed for traffic flow, as that is what is needed for fast route calculation.

- Historical data.
- Truck specific signs/data in the digital map (e.g. truck specific speed limits).

eCoMove research concentrated on directly mapping expected fuel consumption based on historic traffic data. This is an approach that proved feasible, but needs to be targeted to a specific vehicle. Further research would be useful to analyse whether some generic map attribute, e.g. the standard deviation of speed or the average acceleration/deceleration squared, would suffice to estimate average fuel consumption. N.B. Live average speed information is available already today commercially (as output of a cooperative approach), but speed distribution or smoothness is not offered.

Research challenge 3: ***What kind of information and guidance would a driver need in order to find the optimum driving strategy with respect to nearby vehicles and traffic lights, and how can they be predicted in the short and medium term?***

The driver needs to be provided with an advice on how and when to act in combination with information on why an action is required (see challenge 2). The system needs to deal with three elements: the environment, the driver, the vehicle. Each element influences the velocity a driver chooses and hence also influences the optimal driving strategy.

A prediction model needs to include all three elements. Vehicle behaviour is strongly deterministic and hence can be predicted accurately. Literature presents several approaches to predict driver behaviour for certain driving environments. The driving environment is characterised by static attributes (e.g. speed limits, inclination, etc.) and dynamic attributes (e.g. preceding vehicles, traffic lights, etc.). The prediction of driver behaviour in a static driving environment is state of the art. The prediction of driver behaviour in a dynamic environment requires V2X communication to exchange information between participants of the traffic environment. Several simulation environments have been described in literature that aim to simulate driving behaviour in a certain driving environment. However those simulations are not yet deployed in vehicles to predict the driving behaviour. In eCoMove, the ecoSituational Model component predicts driver behaviour (as a prerequisite for velocity optimisation) in a dynamic environment by applying a microscopic traffic simulation considering all information available in the cooperative network.

Research challenge 4: ***What information would an eco-driving assistance system need to receive from the traffic management and control system in order to optimise its advice?***

On the network level, the following information is useful: traffic and environmental conditions (speeds, densities, volumes, emissions/fuel consumption on links), incidents, events, construction works, closures, detours. N.B. In eCoMove, we did not yet cover incidents, events, construction works, closures, or detours. On the level of an intersection, information on the current and predicted traffic light status, as well as speed advice, is useful. Any input needs to be reliable. At the minimum data are needed with a description of the confidence level. The application can then decide whether the data is usable or not.

Research challenge 5: ***How are the principles of eco-driving different for a goods vehicle, and how can they be integrated into a self-learning driver coaching system that adapts for each driver of a particular vehicle?***

In truck driving, the load (influencing the weight of the vehicle) is an important factor. Because of the higher weight, longer coasting is needed in comparison to a passenger car.
In the eCoMove project, modern VOLVO and DAF trucks were used, with automated gearboxes (so no gear advice). Also, a retarder was used as another braking system (for hilly situations) and advice was given on how to use it. This is a different type of advice than would be given in a passenger car. The self-learning part was not explicitly covered in eCoMove (see the desire for adaptability in RQ2; drivers may learn to drive in such a way that advices are not triggered). Per driver settings were available after login.

Research challenge 6: ***Are the principles and factors of eco-driving different for fuel, hybrid or electric vehicles?***

This aspect was not covered in the eCoMove project. The project team expects that:

- Most of the eCoMove approach applies to any kind of powertrain but some advices may need to be adapted.
- The same inefficiencies apply, but factors may have different influences (in other powertrains, compared to conventional powertrains/ICE), and there may be some additional inefficiencies. For instance, coasting advice might need to be revised for hybrid vehicles.

Research challenge 7: ***What data exchange between a goods vehicle, its back-office fleet management system and the traffic management system would be needed to reduce energy losses due to congestion, vehicle stops at red lights and inefficient route choice, and how could these be integrated into one solution?***

To reduce transport logistics emissions efficiently, 3 phases of transport logistics have to be tackled in an integrated approach: *planning, execution* and *post-trip evaluation* as part of a feedback process. During the *planning phase* IT-support in a back-office has to provide efficient planning and optimization algorithms to create robust and efficient trips. Four central aspects influence the fuel efficiency of the transport solution in this phase:

- Order constraints and restrictions to be fulfilled (e.g. delivery time windows).
- Fleet characteristics (e.g. number of available vehicles, vehicle attributes and restrictions).
- Network structure of service area and depot / stop locations.
- Traffic prediction of service area: the average speed on a link in the network, over time.

Another element is “City Logistics” integrated with (public) traffic management, used to steer and coordinate the transport logistics activities of logistics companies. Planned trips are announced to the City Logistics Traffic Management, providing information regarding trip structure and environmental performance. Based on defined static or dynamic or City Logistics rules, e.g. regarding total number of active logistics vehicles in the area or the planned trip performance, access to the city is being granted or denied.

During the *trip execution* phase, a strong interplay between back-office, vehicle navigation and traffic management (traffic state and prediction) is needed to enable an efficient execution. In general, route selection can be done either centrally or in the vehicle. For both approaches, it is important that all relevant information is available for route selection. Centrally, more information may be available. Most information, like e.g. traffic information, can be accessed via a network from a vehicle or a central instance in a similar way. By sending updates from a back office to the vehicle's navigation system, planned stops can be cancelled, additional ad-hoc stops can be inserted and/or the stop sequence can be updated. Depending on the traffic situation, the truck navigation may update the route itinerary between two stop locations.

Integration of several functionalities is needed: route choice influences the navigation and the current route (hence the ecoCooperative Horizon). On the local level, cooperative traffic lights can help reduce the number of stops. This integration has taken place in eCoMove, but needs to be improved for large scale deployment. An aspect to consider is knowledge about the direction the vehicle is taking at an intersection so the most probable path can be calculated more accurately. It is also desirable to adapt the navigation application for touchscreens.

The *post-trip* phase places special attention to the evaluation of the trip performance. Predicted and actual fuel consumption are compared, disturbances during trip execution are analysed. Through this analysis, an improved accuracy of the average fuel consumption regarding vehicle and fleet level can be achieved, which can be used to input / calibrate the average fuel consumption of the vehicle, the route or the fleet as part of the EN 16258 emission calculation standard.

Research challenge 8: ***What information would a traffic management system need to receive from vehicles in the road network in order to estimate overall energy consumption, and how could the system be adapted to minimise the consumption?***

The traffic management system needs to know the current and expected state of traffic and the environment (in this case, CO_2 emissions or fuel consumption) – vehicle positions, speeds and headings, so that traffic volumes, speeds, densities, emissions and emission hotspot severity can be determined and predicted for some time ahead (e.g. 15 minutes). The system can be adapted by redistributing traffic over the different possible routes between all origins and destinations. This can be done by emphasizing (increasing) the costs of environmental indicators in the cost function used in the dynamic traffic assignment. This results in a new distribution of traffic: less vehicles on some routes and more vehicles on other, more efficient routes.

The information needs to become available with very little delay (if possible under 1 minute, definitely not more than 5 minutes for urban networks).
Regarding cooperative traffic control: Vehicles are sending ecoCAM, used by traffic lights for getting priority. These data were not yet used in eCoMove on a higher level scale (city wide network), but this could further improve efficiency.

Further remarks are:

- 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 5 %). 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. In that case, it matters how fast the road users concerned can be informed about the incident and possible alternative routes. When a very fast reaction is possible (advice given within 5 minutes) the reduction can be up to 25 % higher compared to a slower reaction (30-60 minutes).

- Note that in the eCoMove project the routing algorithms and models have not considered slope information of road links (because this information was not yet available). It is possible that with this additional information the effect of optimal routing can be significantly higher than the current results indicate.

Research challenge 9: ***What kind of information and guidance sent by the traffic management system to a vehicle would have the most impact in reducing that vehicle's energy consumption, would such a system be feasible in real operation?***

In order to be able to assess what kind of information would have the largest impact, the inefficiencies, the potential of applications to reduce inefficiencies, and the frequency of occurrence of inefficiencies would need to be ranked (which is not possible with currently available data). The following information is expected to be the most important:

- For urban networks: SLAM and TPEG-RMR (speed and lane advice, and route advice), and priority granted by traffic lights.
- For inter-urban networks: TPEG-TEC and/or TPEG-TFP.

All messages from the traffic management centre need to be checked by the in-vehicle system and may need adaptation to optimise the vehicle's trajectory / trip or be turned into an appropriate advice. Further research in this area could be conducted on how to balance traffic, how to advise routes without causing a situation where advices go back and forth between routes, all the while dealing with different vehicle brands/providers.

Research challenge 10: ***How far can such "in-vehicle strategies" remain compatible with "traffic system strategies", since mutually influence each other?***

Both systems (in-vehicle strategies and traffic system strategies) should not overlap (or at least not too much!). It has to be clear who is responsible where. This requires the definition of clear interfaces (messages) needed between both systems. Also, the issue of possibly conflicting interests between per-vehicle optimisation and global optimisation needs to be addressed. Compliance to advice that are advantageous overall (for the network) but disadvantageous for the individual driver/vehicle cannot be expected to be high. A well designed system will minimise the individual disadvantages and may convince motivated drivers to make "social-aware" routing choices. It should be noted that for traffic light control, compliance rates are less of an issue as these are generally high (red light running is not common).

Conclusions

The eCoMove project tested a large number of cooperative systems and showed that these can help reduce fuel consumption and CO_2 emissions considerably. The main conclusions with respect to the research questions and research challenges are included in this paper. More detailed results can be found in the eCoMove project deliverables on www.ecomove-project.eu.

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