FUEL EFFICIENCY BASED ON ECO DRIVING INFORMATION SYSTEMS

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Abstract
The European Commission (EC) has defined the objective to reduce carbon emission in transport by at least 60% compared to the year 1990. Until 2020 the increase of CO2 emissions shall be limited to 8% [1]. Therefore the EC is funding research projects which are dealing with eco-assistant/information systems such as the within the EU co-funded 7th Framework eCoMove project (Cooperative Mobility Systems and Services for Energy Efficiency) eCoMove. Based on in-vehicle but also cooperative systems such as dynamic eco-navigation, dynamic eco-guidance or other systems that support eco driving, which addressing route choice, velocity profile and traffic control information enable the driver to a more eco-friendly driving style which shall result in reduced fuel consumption. . In order to reach the envisaged goal it is very important that the systems are accepted by the driver and that driver comply with the system's recommendations.

Different methods, such as field trials, driving simulator studies and microscopic network simulations have been applied to verify and validate different applications with the main goal to assess the impacts of eco driving support systems on potential reduction of fuel consumption and carbon emission.

The current paper provides an overview of the methodology used to validate the implemented tools and the findings of the conducted studies.

Introduction

Advanced in-vehicle information based on cooperative systems shall enable the driver to better comply with energy efficient driver behaviour.

Dynamic eco-navigation integrates i.e. the information from the traffic centre, from other vehicles, and different other sources in routing and guidance functionalities. This application not only helps the driver to find the least fuel consuming route but also dynamically adjust the route to changes in the road network and traffic load, as well as guides the driver on the best lane for as low as possible fuel consumption. Eco-driving support systems additionally provide dynamically suggestions to the driver how to drive eco-friendly depending on driving traffic situation – location – road – environment by addressing the driver' driving style and the driver's motivation. Therefore the systems support the drivers suggesting for example appropriate speeds, gears acceleration or deceleration manoeuvres.

The integrative approach of the eCoMove project consists of different sub-systems which assign pre-trip, on-trip and post-trip information to the user [2]. All applications developed are targeting the identified vehicle and traffic inefficiencies [3]. These inefficiencies, along with the use cases defined for the applications, were addressed during a variety of studies. Three types of methods were used to validate the application of eco driving support systems performance:

1. Real-world field trials
2. Driving simulator studies
3. Microscopic traffic network simulations

The great amount of data captured in these studies provides a good overview of the impacts of such systems.

Methodology

The validation methodology of the eCoMove project is based on FESTA evaluation guidelines [4] developed in FP7 research project, which follow a coherent methodology structured in three main phases, i.e., definition, evaluation and impact assessment [see Figure 1].

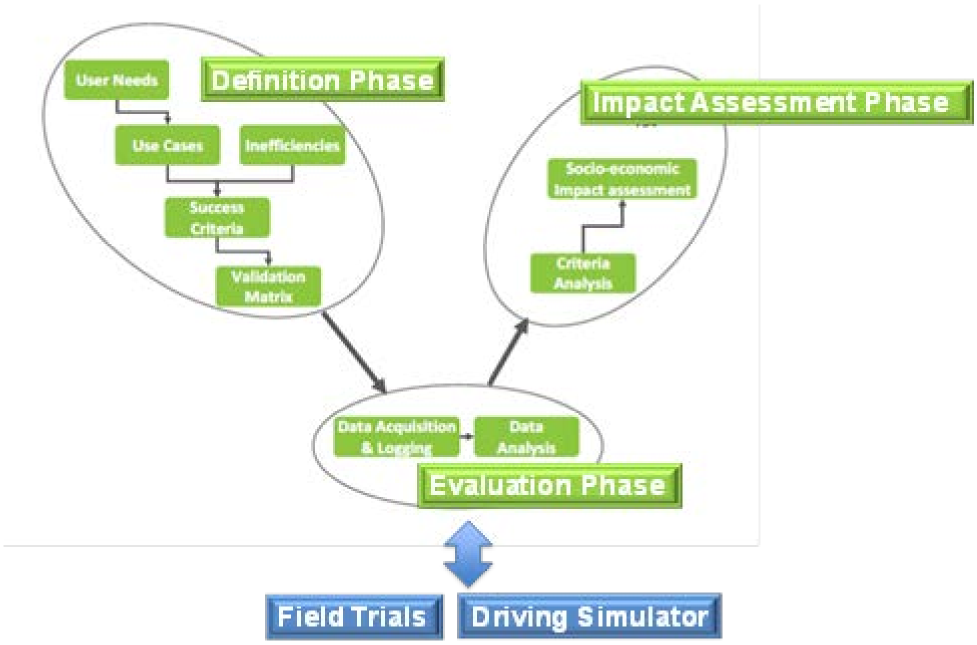


Figure 1 - Evaluation Methodology

FESTA proposes a stringent approach within the definition phase. The first major step of this approach is the detailed formulation of the research questions which are mainly based on the set identified inefficiencies in terms of transport. Objectives and research questions may then affect different impact categories i.e.:

1. Environment
2. Mobility
3. Driver Behaviour
   a. Driver Performance
   b. Safety
   c. Acceptance
   d. Compliance

Based on the projects objectives research questions have been defined and hypotheses with relevant success criteria were derived as thresholds for the indicators [5]. Indicators and their adequate measurement method allow then to answer the hypothesis and their respective research questions (see Figure 2).

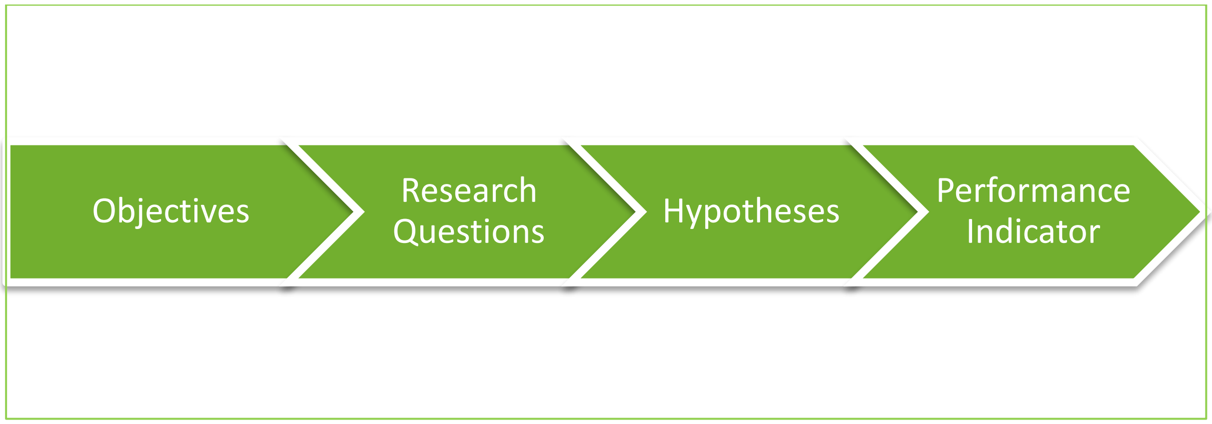


Figure 2 - Definition Phase 1

Following this, scenarios use cases and test setups were designed to be able to answer the research questions by acquiring data from the field, the simulator and network simulation.

With the definition of success criteria and the consideration of situational variables the test setups provide a sufficient amount and quality of data to analyze and assess the single tools and overall system in detail.

Validation scenarios and test cases with a high potential for the reduction of fuel consumption (i.e. scenarios in which inefficiencies are clearly present) are defined. A conducted literature review showed that a considerable fuel reduction can be achieved in use cases involving: route choice, velocity profile and traffic control. These three were considered in aggregated forms and therefore are named Scenario Clusters in the eCoMove context. For a given validation scenario, there is a set of validation test cases that assess the success criteria in the different validation categories. On a first attempt, each validation scenario will determine the performance indicators and test method used for the measurement of each indicator, the set-up of the test (e.g. test site, route, traffic conditions, etc.), the story board, the data to be logged and the number of runs needed.

Each test case is then examined with different test setups in order to analyze different applications in similar conditions. Each test setup defines different measurements eligible to derive performance indicators required for each test case.

Several test cases are clustered in validation scenarios that describe general conditions of the test cases. According to the kind of support for the driver all validation scenarios are grouped into three Scenario Clusters: PreTrip, OnTrip and PostTrip. The general structure proposed for each scenario cluster is presented in the following Figure 3:

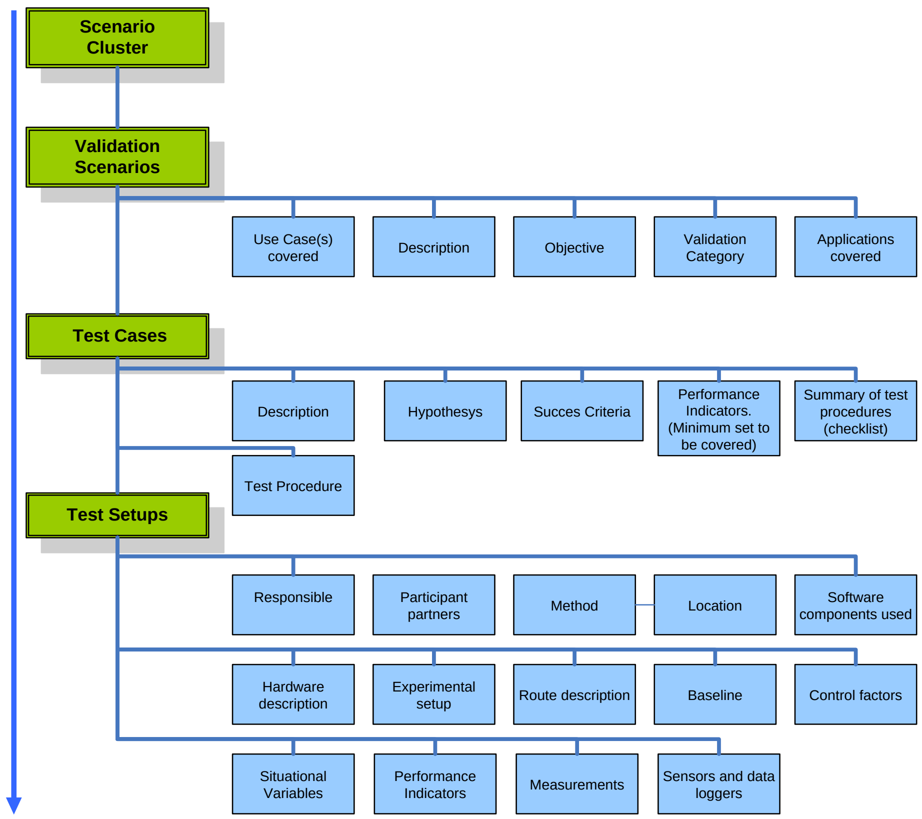


Figure 3 - Definition process of validation scenarios

The scenarios were classified in 3 main clusters in order to have groups of applications with points in common regarding the validation process.

Following this approach, these 3 clusters were classified:

- Cluster 1: Pre-trip
- Cluster 2: On-trip
- Cluster 3: Post-trip

Finally, there have been more than 80 test setups defined which result in a large amount of measured data that have been collected. These data were then used to calculate the performance indicators adequately to the focused impact categories. The follow up action was a detailed statistical analysis of the performance indicators. To illustrate the range of efficacy of the performance indicators, BoxPlots have been applied. A comment window at the end of the table allows to state remarks and first pre-assessments [Figure 4].

ECOM-PI-101: **Fuel consumption per car per origin destination (OD)**

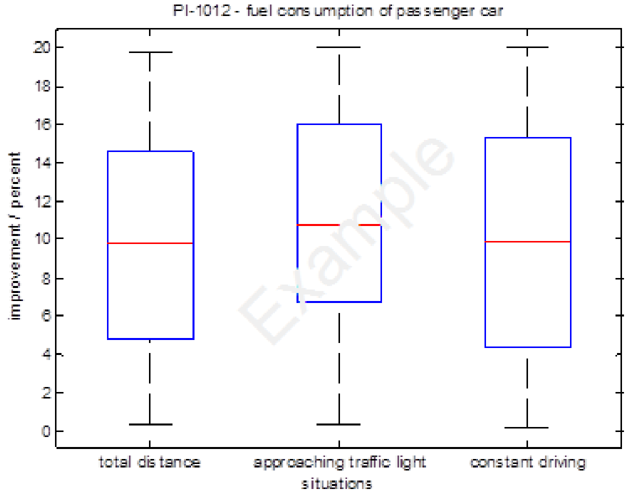
Description: Changing of fuel consumption per passenger car between baseline and treatment (baseline = 100 %)

Unit: per cent (fuel consumption in litre/100km)

Results:

Situation	Mean	Standard deviation	Median	Percentile P25	Percentile P75	t-Test	effect size
Total distance	10 %	7 %					
Approaching traffic light							
Constant driving							

Graphical presentation of data analysis:



Comments:

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Figure 4 Analysis Template

The detailed statistical analysis of the performance indicators provides a very good picture of the test setup within the focused impact categories. But this picture is also limited to the system and technology applied and the testing environment. However, it provides no overall result. Therefore the main objective of the assessment strategy was to find a harmonized approach being able to compare the different studies with its specific circumstances (as encountered in the tests) to finally avoid misinterpretation of the results. A descriptive analysis by considering mean values, standard deviations, medians as well as the effect sizes was conducted. The t-test showed then, if a significant differences between the treatment and baseline trial could be detected.

Test Setup Design

Different trials have been designed to evaluate the potential impact of eco driving support systems on fuel consumption and CO_2 emissions. The following Table 1 presents the performance indicators and their relevant unit that have been considered for data acquiring and analysis:

Table 1: eCoMove Performance Indicators (subset)

	ECOM-PI	Description	Unit
Environment	101	Fuel consumption reduction of passenger car	%
	102	CO_2 reduction of passenger car	%
	103	Fuel consumption reduction of truck	%
	104	CO_2 reduction of truck	%

Although fuel consumption and CO2 are directly correlated The design of the test setup varied in the test route characteristics to identify routes with the highest potential: i.e. urban, rural or mixed routes, traffic lights, roundabouts but also the route length. Furthermore, the number of test participants differed between the testing methods. A large difference was mainly between the driving simulator studies and the field trials. The main reason for that was because of the costs and the fact that only employees were allowed to drive with the companies' trial vehicle.

Results

The impact assessment of the eco-information systems developed, verified and validated within the eCoMove-project provides a statistical analysis of different study results with different sample sizes and different effect sizes [6]. Since the overall validation approach was strictly applied by all test setups the results of the single studies could be easily compared. No additional effort was necessary to code and calculate the relevant values.

Within this validation category environment the most important performance indicator fuel consumption (ECOM-PI-101) was analysed. The following figure gives an overview of the outcomes from the different studies. Due to internal agreement between the partners the test setups have been coded for privacy issues. In fact the detailed description of the results provides a very well overview of the different trial situations and methods used.

The range of fuel consumption reduction for the car studies was between 4.5% and 25.1% while most of the studies had mean reductions between 10% and 20%. Looking at the different test setups it becomes obvious, that the fuel consumption reduction was higher on urban streets with many traffic lights. As shown in the simulator studies one situation with a high fuel reduction potential (more than 20%), which was shown in two different driving simulator studies is a red traffic light which will switch to green before the drivers arrive when they follow the speed reduction recommendation beforehand.

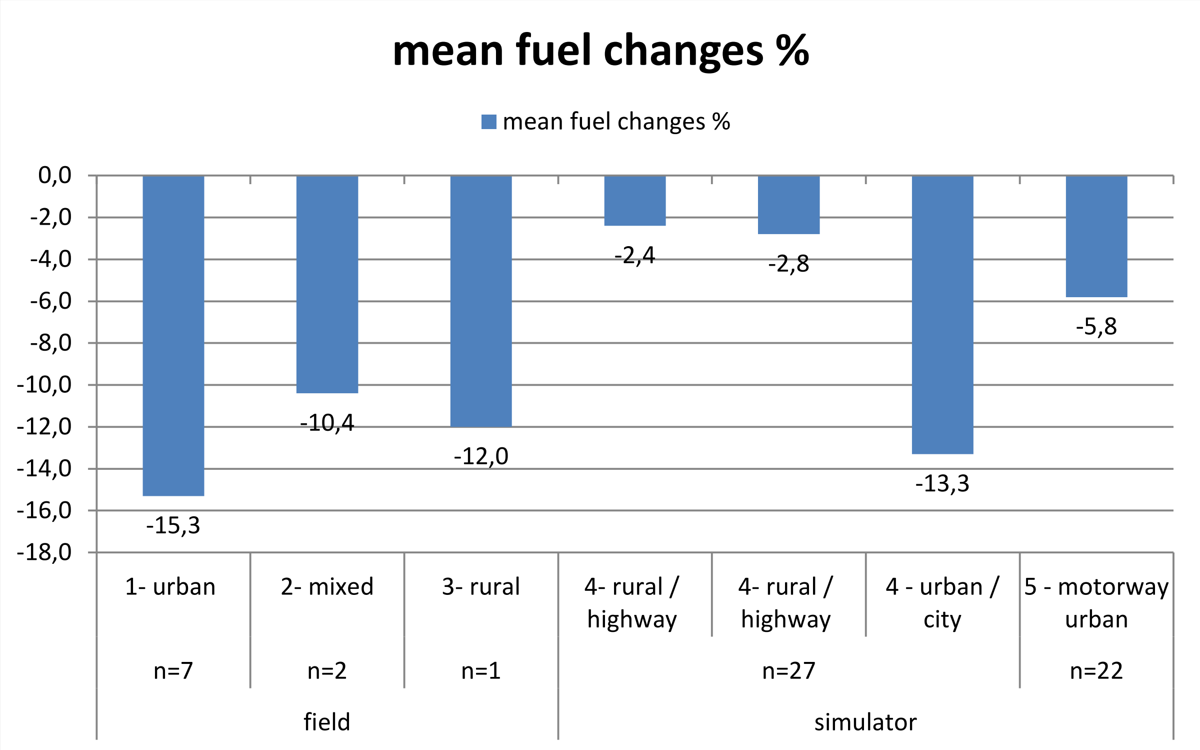

Figure 5 mean fuel reductions in field and driving simulator studies for private cars (%)

Other situations with a very high fuel reduction potential are situations where the drivers have to slow down because of speed limits, curves or stop signs. However, those situations have been tested only in the simulator and asked about their subjective impressions many participants felt patronized by the systems recommendations, especially haptic feedback pedal. As it can be seen, the fuel reduction on rural roads or motorways was also relatively low. The reason for that was that the applied system does primarily have an effect on urban roads with several traffic lights.

Several eCoMove applications require a certain penetration rate to take effect; these applications were simulated in network simulations rather than demonstrated in reality. The summarized results of the realized traffic network simulations were the basis for the comparison with the results of the field and driving simulator studies.

The following applications were researched within the project:

- Traffic Signal Control (dynamic green waves, cooperative traffic lights, balanced priority)
- Network Usage (analyse the accuracy of actual, predicted and desired traffic states of the traffic network i.e. flows, speeds and travel times, and analyse the effects of using traffic strategies derived from these states
- Driving Behaviour (ecoInformation, ecoApproach, etc.)
- Route Guidance
- ecoMM (Motorway, On-Ramp-Meter)

In their vast majority the simulation results confirmed the expectations especially concerning the reduction of CO_2 emissions ranging up to (and sometimes beyond) ten percent. Some notable side effects were discovered, the major one being that the eCoMove applications Green Wave and Approach Advice do not work together.

In detail, the eCoMove applications in the field of traffic signal control showed good results concerning the reduction of CO_2 emissions. The eCoMove applications for traffic management and control showed an average reduction of emissions exceeding ten percent through better traffic distribution. Also, eCoMove driving behaviour support was found to reduce CO_2 emissions and in this sense also fuel consumption. In parallel, the eCoMove route advice was seen to reduce CO_2 emissions in the lower one digit percentage range.

In detail, the eCoMove applications in the field of traffic signal control showed good results concerning the reduction of emissions.

Discussion

The comprehensive approach of emission reducing measures is very innovative and requires a variety of methods to validate the outcome. eCoMove followed this requirement by applying three different methods which realize validated results.

In most of the studies the application of eco driving support systems might be a good approach to strengthen the driver's awareness and the willingness to save fuel. Within the trial studies it became apparent that it is highly dependent on the driving situations how much fuel could be saved. Situations with the highest potential were often in urban surroundings (speed limit 50 – 70 km/h) at traffic lights. Especially when approaching a red traffic light, which was about to switch to green, the information through an eco-driving support system, which is capable of communication with the traffic light, could lead to great fuel reductions close to or in some cases even above 20%, depending on the recommended target velocity. Using these mechanisms unnecessary deceleration and acceleration and therefore unnecessary stops could be reduced substantially. In other situations it is questionable in which driving situations the drivers should be supported. There were some situations, e. g. curves, stop signs or roundabouts where the drivers were a little bit more sceptical about the support. A better quality check and approval of the information management within the on-board systems needs to be implemented for further studies.

The results of the microscopic traffic network simulations also show beneficial effects of network related applications on the reduction of CO_2-emissions of the whole network. The range of the emission reductions seemed to be in a similar range as the results of the field and driving simulator studies.

The conducted studies finally provide a very good picture of the potential benefit of cooperative ITS systems to reduce fuel consumption and CO2 in transport.

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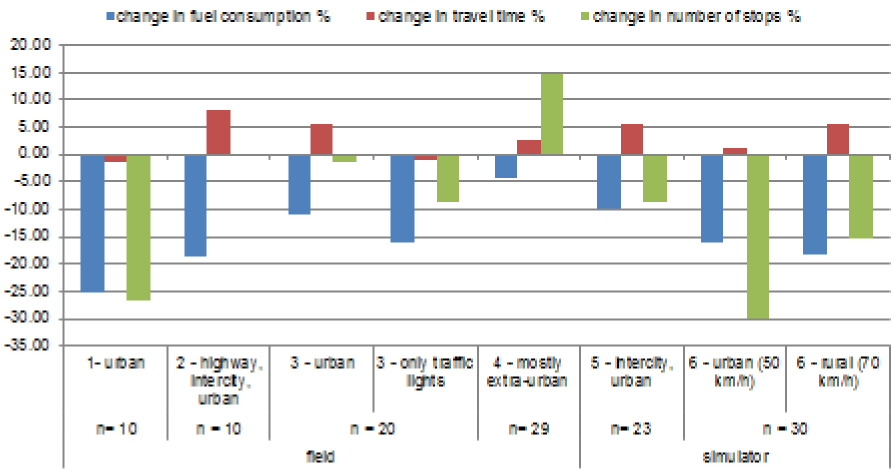
Cars – fuel reduction, travel times, and number of stops



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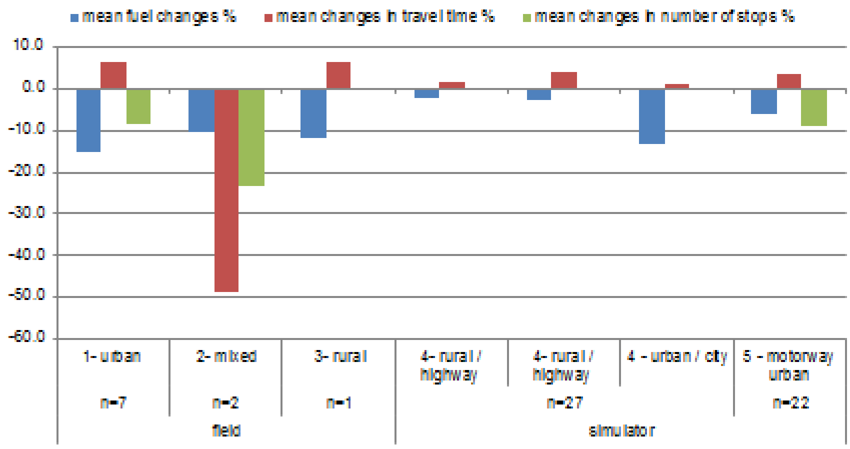
Trucks – fuel reduction, travel time & number of stops



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