Study on CO2 benefit through Cooperative Systems

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ABSTRACT

Broad activities are currently ongoing to reduce fuel and in consequence CO2 in the field of transport. Advanced driver information based cooperative systems are developed with the goal to help the driver to perform a more eco-friendly driving style with the result to safe fuel. Reaching the envisaged goal it is very important that the systems are accepted by the drivers and that drivers comply with the systems recommendations. In this regard also a negative influence of eco-driving with impacts on traffic performance and safety has to be avoided. The motivation of the present paper is to show the validation and assessment approach to reveal these side effects of eco-information systems of the EU co-funded 7th Framework eCoMove project (Cooperative Mobility Systems and Services for Energy Efficiency).

Keywords: Driver Assistant Systems, CO2 reduction, Cooperative Mobility and Services, Driving Simulator Study, FESTA methodology

1. INTRODUCTION

The assessment of the impact of eco-friendly driving based on cooperative intelligent transport solutions which optimize the network-wide traffic management and control as developed in the project eCoMove, requires different methods to reveal possible side effects.
The study is mainly based on the highly relevant FESTA-methodology [1]. Specific eCoMove needs were adapted to a comprehensive validation and assessment concept [2]. The defined evaluation approach is a combination of different methods following:

1. Questionnaire
2. Small scale field trials,
3. Driving simulator studies and
4. Microscopic traffic network simulations.

Then the aim of the validation is whether the eCoMove system is able to reduce fuel consumption and CO2 emissions by 20%.

2. COURSE OF ACTION

In the very beginning of the project different vehicle and traffic inefficiencies were identified, which hamper an eco-friendly driving. Cooperative systems were developed to encounter these inefficiencies from the technical side. Examples for the technical development are i.e. intelligent speed and distance adaptation, intelligent routing and information to unnecessary electronically consumers, tire pressure or payload. But most of the tools just succeed if the driver follows the made recommendations. Therefore the designed validation and assessment methodology focus on a variety of research questions and hypothesis which consider not only the single tool but also the overall system and the driver acceptance. In this regard four impact categories have been identified to reflect the possible impact of the applied cooperative ITS tools:

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

Applying the before mentioned four methods for evaluation a harmonized set of measures to be analyzed is required. Based on these measures indicators can be retrieved that ensure consistency between the test methods when analyzing the available data. With the definition of success criteria and the consideration of situational variables the four methods will provide a sufficient amount and quality of data to analyze and assess the single tools and overall system in detail.

Figure 1[7] summarizes the validation and assessment methodology applied in this study:

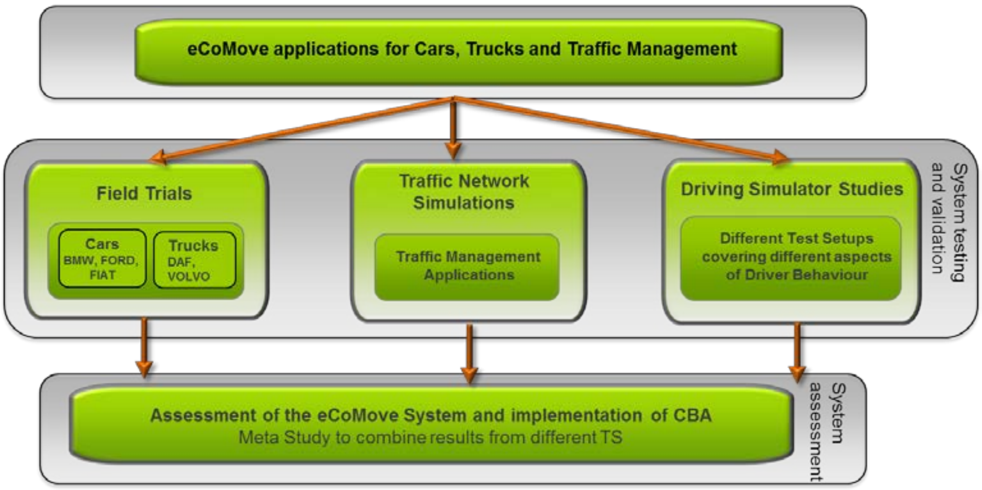

Figure 1: Validation and assessment methodology

2.1 Questionnaire

The objective of the questionnaire design was to combine questions focusing on the acceptance of technical systems are dependent on the perceived usefulness and the perceived ease of use as well as the behavioral intention and the attitude toward using the system. The design is based on the Technology Acceptance Model (TAM) originates developed by Davis [3]. The questionnaire allows then to acquire different data of different focus groups such as private car drivers and truck drivers which are considered within the project.

2.2 Small Scale Field Trials

The ITS tools developed by the project partner are currently in the integration phase. After finalizing this crucial phase verification and validation tests on the field were be conducted by the OEM and technology provider. Due to the fact that the systems and components are under development only internal staff will be allowed to take part on the small scale field tests. In addition it is to mention, that the ecoMove project is not designed as a field operational tests and therefore to large scale testing is not foreseen.

2.3 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 driving with the aim to reduce emissions. Reaching 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 the driver simulator studies the developed ecoDrivingSupport applications for private car drivers and the ecoCoaching applications for trucks were validated. These systems apply the inefficiencies of:

- Inefficient acceleration
- Inefficient deceleration
- Inefficient idling
- Inefficient speed
- Inefficient gear

Therefore the velocity profiles including acceleration/deceleration, the gear shifting behaviour and the 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 realize a variety of driving situations but also different HMI designs and information strategies.

2.4 Microscopic traffic network simulation study

Since the project was not designed as a large scale field operational test the number of equipped vehicles is very limited. Hence, most eCoMove infrastructure applications refer to macroscopic aspects of the road traffic and the evaluation of the impacts of those applications requires a statistical analysis with a larger sample.

A microscopic traffic network simulation can substitute the large scale field operational test and allows "ceteris paribus" studies of all necessary parameters by the ability to reveal 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 can model the functionality of innovative applications rather realistically including driver-vehicle interaction but also the interaction between equipped eCoMove-vehicles as well as equipped and non-equipped vehicles. It allows determining vehicle related effects (stops, delays, energy, and emission) on traffic management but also on combinations of eCoMove applications.

As simulation tool a VISSIM traffic simulation environment will be used. Calibrating the simulation, speed profile data from the different simulator study scenarios are used which promise high quality results. Later on different equipment ratio can be simulated and visualized which is not possible in real environment tests within the project.

3. SYSTEM AND TECHNOLOGY APPLIED

The integrative approach of the eCoMove project consists of different sub-systems which allow pre-trip, on-trip and post-trip information to the user [2].

Pre-trip-information applications provide information regarding inefficient vehicle conditions which leading to a negative effect on fuel consumption. The driver will then be able to solve these inefficiencies adequately (ecoInformation). Besides that pre-trip-information support an efficient route choice based on available traffic state prediction. Especially for freight transport and logistics the so called ecoTripPlanning application takes into account the available time slot, parking availability and calculates then the optimal start time and optimal route to minimize fuel consumption.

On-trip-information application addresses inefficiencies while driving and recommend possibly readjustment of vehicle conditions that might influence the eco-behavior of the vehicle. Further, while driving and given a destination, the remaining route will be continuously recalculated by taking all available information into account. Also, if no destination is given, but the expected route can be based on the most probable path of the ecoCooperativeHorizon, actual information about traffic state in the vicinity of the vehicle may lead to (micro-level) route alternatives.

Additional on-trip information focusing on the drivers driving style (ecoSmartDriving system), which dynamically provides recommendations to the driver how to drive eco-friendly depending on driving traffic situation, location and road typ. The essence of the system is that it is a forward looking eco-information function that provides dynamic advice in a medium-to-long term perspective on how to drive (e.g. advance speed recommendation, gear, acceleration, deceleration consumption prediction).

4. DATA ANALYSIS

According to the impact categories defined (see chapter 1), different indicators have been identified to measure the performance of the study subject. Based on examples Table 1 provides a short overview of the focused impact categories and relevant indicators.

Impact Category	Environment	Mobility	Safety	Acceptance
Performance Indicator	Fuel consumption of passenger car Fuel consumption per car per origin destination (OD)	Total travel time Number of stops	Critical TTC, in s Standard deviation of speed, in km/h	Use of the system Ease of use Understanding of message

Table 1 Impact Category and the relevant performance indicators used (examples)

Acquiring the necessary data to calculate the performance indicators, different categories of measures have been applied (Table 2). The variety of studies conducted were using a selection of the below measures [8].

Measure category	Description
Direct (raw) measures	A direct measure is logged directly by a sensor, without any processing before saving the data to the log file, coming from the CAN bus of the vehicle, for instance.
Derived measurements	A pre-processed measurement is not directly logged by a sensor, but either a variable that has been filtered or which is a combination of two or more direct or derived measurements e.g. CO2 emissions derived measurement from fuel consumption measurements.
Events	Peculiarities based on direct and/or derived measures. They can be short in time, or extended over a longer period of time. One or several precondition must be fulfilled for an event to be classified as such, that is, one or more „trigger" criteria must be exceeded.
Self-reported measurements	Measurements that are obtained from questionnaires, interviews, rating scales, etc. used, for instance, when measuring the user acceptance criteria.

Situational variables	Current external surroundings and the external influences during the testing. Situational variables can be logged like direct measures or computed like derived measurements. They can also be self-reported measurements or events. In any case, all relevant situational variables have to be measurable continuously, such as time of the day or weather conditions.
Control factors	Determine the parameters that have to be controlled during the test of the hypothesis to ensure that these factors do not disturb the comparability, e.g. same driver.

Table 2 Measures Categories

The definition of validation scenarios and test cases followed the approach of scenarios with a high potential for the reduction of fuel consumption (i.e. scenarios in which inefficiencies are clearly present). 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 can be considered aggregated forms and therefore are going to be named Scenario Clusters in the eCoMove context. For a given validation scenario, there will be a set of validation test cases that will assess the success criteria in the different validation categories. On a first approach, 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.

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. Pretrip
- Cluster 2:.Ontrip
- Cluster 3: PostTrip

Finally, there have been more than 80 test setups defined which result in a huge 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 the detailed statistical analysis of the performance indicators. 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 and 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 specific circumstances (as encountered in the tests) to finally avoid misinterpretation of results found. Using the method of a meta-analysis provides a very valuable approach.

5. RESULTS

Various trials under participation of volunteers have been conducted in the field and in the driving simulator. The participant share ranged from 18 – 24 per study while consisting of professional truck driver, company employees or random sampling of a volunteer pool.

A harmonized 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 CO2 reductions over all studies found so far is between 5-25%. These results vary and are very depending on the use case but also on the (combination of) applications tested. Also, effects may be local. Coming up steps will consist of sorting out all the results by taking into account the conditions during tests. The values will then feed into the meta-analysis and provide a concrete effect size of eco-information systems. By now, detailed preliminary results within the different studies and impact categories are only available but will be presented in the following.

Impacts on Environment

Field Trials Car

Within the field trials with private cars a fuel reduction between 11% - 13% could be identified. As major influencing factors of fuel consumption mostly electric consumers and driven speed are account for these effects.

Driving Simulator Study Car

The driving simulator studies with private cars showed a fuel reduction by 9.7% with a standard value of 5.6%. This result is based on earlier reaction times and in this regard the earlier beginning of coasting.

Driving Simulator Study Truck

A fuel reduction by 6% on average could be identified within the driving simulator studies for trucks. 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

Within the impact category mobility no significant measurable difference between baseline and treatment for the performance indicators travel time, number of stops etc. could be identified. At least a first analysis of the truck simulator study showed in some situations a 5%

longer travel time with the assistant system. Further analysis is needed to identify possible mismatches.

Impacts on Acceptance

The acceptance of the experienced system was very high. The participants also assessed the system as very useful and effective. It could be observed that most drivers liked and used the system to change their deceleration behavior. Overall the system scores at high average especially for easy learning and ease of use.

Impact on Safety

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

Impacts on Driver Behavior

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 behavior changed to an earlier shifting and lower acceleration when using the system. Additionally, engine brake and roll-out phases increased. The drivers showed a more harmonized driving style with less breakings and lower gas pedal positions. Hence, the number of stops could not be reduced in some studies. Also the travel time was about 5% longer with the eco-information system.

6. CONCLUSION

The comprehensive approach of emission reducing measures is very innovative and requires a variety of methods to validate the outcome. ECoMove follows this requirement by applying four different methods which enable to realize validated results. The conducted study then provides a very good picture of the potential benefit of cooperative ITS systems to reduce CO2 in transport.

A first assessment of the preliminary results showed a reduction of fuel consumption by about 5-25% based on a more anticipative driving. The participants generally followed the advices but some also experienced a certain stress level due to complex HMI design and information. Finally, no negative effects on traffic safety or on mobility could be observed and even truck drivers are willing to use such systems.

The combination of the specific eCoMove results of the conducted trials and the results of the intensive review of the literature will then allow a comprehensive assessment of eco-information systems regarding their impact on driving behavior and environment. The envisaged use of a meta-analysis method therefore extends the primary research results of the project with external project results to realize finally a more rigor and robust assessment.

Assessing the impact of the different methods through a scaling-up approach allows finally information to a city impact depending on different equipment ratio.

7. ACKNOWLEDGEMENTS

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