Challenges in analysing data from a field operational test of advanced driver assistance systems: the euroFOT experience

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Abstract

This paper discusses the challenges in analysing the data from the large scale field operational test (FOT) to be conducted within the EC euroFOT project. The euroFOT project aims to investigate the impacts of advanced driver assistance systems (ADAS) and to encourage their deployment. Started within the EC’s seventh framework programme, the euroFOT project will evaluate, using instrumented vehicles in real traffic conditions, the impact of ADAS on driver performance, safety, the environment, traffic efficiency and user acceptance. The approach derives from the FESTA handbook [1], which provides guidelines for conducting field operational tests. The FESTA handbook approach is being adapted according to the specific requirements of the euroFOT project. Altogether five Vehicle Management Centres (VMCs) are coordinating the fleet of vehicles being evaluated in the euroFOT project, which consists of approximately 1000 vehicles. Data collection will start in January 2010 for a period of one year.

1. Introduction

The euroFOT project is the first large-scale Field Operational Test (FOT) of multiple advanced driver assistance systems (ADAS) in Europe. Several FOTs have been conducted previously in Europe (see [2], [3] and [4]). However, euroFOT is the first study to have attempted to coordinate within a single FOT a series of FOTs conducted across Europe using common
methods for collecting, uploading, processing, analyzing and reporting the FOT data. EuroFOT will evaluate, using instrumented vehicles, the impacts and acceptability to drivers of ADAS in a real traffic with normal drivers. Altogether, about 1000 vehicles equipped with nine different ADAS technologies will take part in the FOT. The vehicles have been produced by a range of manufacturers, and will be driven by around 1000 drivers. The project duration is 40 months and it will end in August 2011.

The euroFOT project is investigating systems that are already on the market or sufficiently mature enough to be tested as commercial applications. Based on the recommendations from existing roadmaps and on the availability of well-developed systems, the following group of nine functions has been selected for evaluation in euroFOT:

1. Longitudinal functions:
   - Adaptive Cruise Control (ACC), Forward Collision Warning (FCW), Speed Regulation System (SRS).

2. Lateral functions:
   - Lane Departure Warning (LDW), Impairment Warning (IW), Blind Spot Information System (BLIS).

3. Other functions:
   - Curve Speed Warning (CSW), Fuel Efficiency Advisor (FEA), Safe Human-Machine Interaction for Navigation Systems (SafeHMI).

The FOT will be conducted by most VMCs for a duration of 12 months. The first three months will serve as a baseline period during which the functions will be deactivated, while data on driving performance (e.g., vehicle speed, acceleration, etc.) and behavior (e.g., eye glance durations) is collected from various sensors. During the remaining time (the treatment period), the functions to be tested will be activated, and the same driving data will continue to be recorded. Drivers will hence act as their own experimental controls. Comparisons between recorded driving behavior and performance data for the same participant in the treatment and baseline periods will be made, in order to assess the impact of the functions. There will be a separate control group for only one VMC; for all others, surrogate measures will be tracked over time to ensure that the data on the impact of the functions are not confounded by seasonal and other factors. During the Treatment period drivers will be free to activate and use the functions as they normally would, so that their interactions with the functions are recorded under natural circumstances. During the entire trial a driver liaison officer from each VMC will remain in direct contact with the drivers to ensure that the FOT proceeds as planned (more information in [5]).

The chosen functions will be tested in different vehicles supplied by different European OEMs using different data acquisition systems for logging different data (CAN-data, video, GPS etc.). The FOT is being carried out at various test sites across four countries in Europe, which are managed by the VMCs. The analysis of the data will focus on the following three issues:

- User acceptance and user related aspects
- Impact assessment
- Socio-economic cost-benefit analysis

The user acceptance and user related aspects as well as the impact assessment will be discussed within this paper. The socio-economic cost benefit analysis will be based on the results of the impact assessment. The impact of each tested function with regard to safety benefit, traffic
efficiency and environmental impact will be translated into monetary benefits. The benefits will be calculated in general, and for different vehicle penetration rates. The approach of the evaluation is specified in a “data analysis plan”, developed for each VMC.

Within the definition of the data analysis plan – which prescribes the approach for how to analyze the collected data - several challenges were identified:

- adaptation of the FESTA handbook methodology to the specific needs of euroFOT
- handling the large amount of data from many different data sources
- automatisation of evaluation process, due to the large amount of data
- ensuring that all pre-defined research questions are addressed, despite vehicles being equipped with different sensors
- development of a common questionnaire to record subjectively reported measures for the evaluation, due to the absence or unavailability of appropriate vehicle sensors
- designing a complete analysis, from data acquisition through to impact assessment, considering the needed input for the cost-benefit analysis. This involves integrating various existing methodologies and filling in some remaining gaps
- translation of surrogate measures into accident reduction potential, for different penetration rates for the functions within the vehicle fleet

The following sections describe in detail the approach and the challenges of the impact assessment as well as the user acceptance and user related aspects evaluation.

2. Data analysis plan

The data analysis plan for euroFOT describes the procedural steps to analyze the massive amount of data collected from the FOT (at the German1-VMC approximately 12 TB for 240 vehicles), in order to answer the pre-defined hypotheses and research questions of interest. Adherence to the data analysis plan will ensure that each partner has a clear understanding of how to analyze the available data, taking into account all the common and specific requirements of euroFOT.

The structure of the data analysis plan was derived, to a large extent, from recommendations made in the EC-funded FESTA project handbook; but for each step of the data analysis process (e.g., hypothesis formulation, performance indicator calculation etc.), choices have had to be made to tailor the FESTA methodology to the specific needs of euroFOT, which was one of the major challenges in developing the data analysis plan. The data analysis approach is illustrated in Figure 1. At each VMC, the data is collected from the test vehicles (e.g. speed and headway measurements with a 10 Hz frequency). The relevant data is extracted and checked with regard to data quality. Before the data is stored in the database, it will be enriched with additional information (e.g., information from digital maps, based on GPS information). This process chain will be managed by the euroFOT sub-project “Data management” (SP3). The data analysis will start when the data is available in the database. At each step, the quality of the data is checked again.
The database contains a huge amount of data, which will be clustered into specific events (e.g. overtaking manoeuvres, lane changes etc.) and situational variables (e.g. weather condition, number of lanes, road type etc.), in order to optimize the analysis of the data by considering only relevant data sets. These steps are being performed automatically within the data processing part. The quality of the data will be checked within sub-project 3 and afterwards within the analysis phase after each process step, in order to assure the evaluation of valid data.

Using the clustered data, performance indicators (PI), such as average speed or time headway, are calculated. Each PI is used in the testing of hypotheses that have been specified by the consortium partners. There are hypotheses relating to the various types of impacts and user related aspects, e.g. "ACC increases average time headway". To limit the organisational complexity of the analysis, it has been divided into a VMC specific part and a common part. The common part consists only of the analysis of functions that are tested by more than one VMC. In this way, the majority of the work is delegated to the VMCs, but it is realised according to a common approach that enables integration of the results.

The approach described above provides a way to reduce an enormous data set into a limited number of indicators that enable further analysis. Additionally, in order to determine unexpected relationships in the large data sets, an exploratory data analysis (data mining) will be conducted. The results will be used for the global assessment. To scale up the impacts of the tested functions the global assessment will be carried out. Within the quality assessment, a review of all performed steps will be applied, in order to ensure that the whole analysis chain process is completed properly. Finally the results will be provided, in order to perform the cost-benefit analysis.

By definition, the results of the FOT derive from only a small sample of the overall traffic in Europe. For this reason, simulations of scenarios with higher penetration rates will be carried out for scaling up locally determined effects within the global assessment phase. For this, micro-

Figure 1  Data analysis approach in euroFOT
simulation as well as further models will be applied to estimate direct and indirect traffic as well as environmental impacts.

3. User acceptance and user related aspects

A major focus of the euroFOT project is on driver acceptance of the ADAS technologies, and their impact on driver behaviour. Work package (WP) 6300 of the project is responsible for the analysis of data that sheds light on these issues. Specifically, WP6300 will address the following issues:

- the impact of the selected systems on driver behaviour (e.g., on drivers’ intention to use the system after the completion of the study);
- the impact of the selected systems on driving performance (e.g., on the following distances drivers adopt when following a lead vehicle);
- the impact of the systems on perceived driver workload (e.g., on driver ratings of driving workload before and after use of the system);
- user acceptance of the systems – in absolute terms and over time with system use. The following issues are identified for analysis within the euroFOT project: usability, usefulness, trust, usage, and social acceptance;
- user practices (i.e., changes in the way drivers use with the system over time); and
- misuse and abuse of the system (i.e., use of the system in ways not intended by the designers of the system).

From an analysis perspective, addressing these issues has, and will, pose some significant challenges, some of which have already been alluded to. Chapter 9 of the FESTA Handbook describes the general challenges associated with data analysis and modelling in the context of an FOT. Some of the special challenges associated with analysis of the data in WP6300 are mentioned briefly below.

3.1 From hypotheses to measures

The analyses to be undertaken in WP6300 will derive principally from the hypotheses previously formulated. While some of these are system specific (e.g., “Using ACC, the minimum time gap to the leading vehicle will decrease”), others are generic and common to all of the systems to be tested (e.g., “Driver workload decreases over time with system use.”)

A major activity in euroFOT has been the definition of performance indicators (PIs) that enable the above-mentioned hypotheses to be tested. For most of the formulated hypotheses, the collected measures (e.g., “steering wheel angle”) and their associated PIs (e.g., “maximum steering wheel velocity”) can be derived directly from the vehicle data acquisition system. In WP6300, however, many of the PIs are subjective (e.g., “perceived mental workload”) and require subjective measures (e.g., a score on subjective mental workload questionnaire rating scale). In the context of an FOT, the selection of appropriate subjective measures poses three main challenges:

- For subjective PIs, is it better to obtain relevant measures via driver interviews, questionnaires, focus groups or a combination of these approaches? A fine balancing act is necessary in order to yield the required data. Questionnaires need to be short, as previous experience with FOTs has shown that drivers may not complete them if they are too long, or if there are too many of them. A short interview might be better for obtaining answers to questions which are complex and open-ended (e.g., “Do you use the system differently now from the way you did when you first started using the system?”).
The FOT is a maturing methodology, and for some subjective PIs there currently exist no valid, reliable and standardised measures. “Acceptance”, for example, has been loosely defined, and “models” of its underlying dimensions (e.g., “perceived satisfaction”) are rare.

There exist many questionnaires that can be used to measure attributes of human behaviour. In FOTs, it is critical to use target questionnaires that yield data that can be readily analysed; and if they do not exist, to ensure that they are designed in a way that facilitates and supports data analysis.

3.2 Linking of subjective and objective measures

There are 3 fundamental reasons for collecting subjective measures in an FOT:

- to collect data (e.g., on perceived mental workload) that cannot, for technical or other reasons, be collected via the vehicle data acquisition system;
- to understand why a hypothesis tested does not yield an expected result; for example, to understand why a frontal collision warning system failed to have a noticeable impact on driving behaviour (e.g., the driver may have found the system irritating and masked the warnings in some way undetectable by the data acquisition system);
- to test whether the systems under investigation have a differential effect on different driver sub-groups; for example, by collecting measures of certain driver characteristics (e.g., propensity to take risks), it is possible to determine whether “risk takers” derive more or less benefit from a system than those who are not so inclined.

The challenge in an FOT is to ensure that the subjective measures can be directly linked with the objective measures. It is especially important to ensure that information gathered on the acceptability of the systems can be linked with the observed impacts of the system on behaviour. In this regard it is also important that categorical or ordinal data, such as that from questionnaires, is analysed appropriately.

Subjective performance indicators are different from those derived from logged vehicle data as they cannot easily be “sliced” according to different situational variables. For example, a measure of “perceived satisfaction” obtained from a questionnaire every three months cannot easily be related back to a specific road type or driving situation.

3.3 Evaluating combinations of systems

Increasingly, OEMs are selling ADAS systems as a combined option; for example, FCW combined with ACC. Sometimes two or more such systems are implemented by the same system, and cannot be activated independently. In the euroFOT project, five of the participating OEMs will test combined functions. Whilst it is especially interesting to evaluate the combined impact of more than one system function on driver behaviour, driving performance and acceptance, the fact that the systems are combined makes it difficult to assess the impact of the systems on these parameters in isolation. A major challenge will be to determine how to analyze the data in a way that enables the relative impact of the systems, alone and in combination, to be quantified.

The outputs of WP6300 will also inform analysis activities in WP6400, which is concerned with quantifying the impact of the systems on traffic safety, traffic efficiency and the environment. The data analysis challenges of WP6400 are described below.
4. Impact assessment

This section deals with the impact assessment and its specific challenges. These have to do with:

- the need to design a complete analysis from data acquisition to the impact assessment,
- the difficulties in translating surrogate safety measures into accident reduction potential.

4.1 General set-up impact assessment

The objectives of the impact assessment are:

- to analyse the effects on the EU level for the functions tested on traffic efficiency, safety and the environment at various penetration rates (low / medium / high),
- to provide input for the cost benefit analysis.

The impact assessment translates effects found for the equipped fleets and trips made in the FOT to the EU level. This means scaling up of the effects found in the FOT data, in certain situations, or for certain groups of drivers. This leads to an understanding of the effects of functions if they would be used in the entire European Union (by a small or larger part of the drivers).

Furthermore, the impact assessment needs to provide input for the cost benefit analysis (CBA). The CBA in euroFOT requires information about the costs of the functions and the benefits. The benefits are derived from the impact assessment. The impacts to be quantified for use in the CBA are presented in the figure below.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic efficiency</td>
<td><strong>direct effects</strong>: travel time changes for CBA, but also homogenisation/</td>
</tr>
<tr>
<td></td>
<td>reduction of congestion effects for environmental impact assessment;</td>
</tr>
<tr>
<td></td>
<td><strong>indirect effects</strong>: changes in the amount of accident related congestion (based</td>
</tr>
<tr>
<td></td>
<td>on changes in number of accidents)</td>
</tr>
<tr>
<td>Traffic safety</td>
<td>changes in the number of accidents with fatalities, injuries (severe, slight)</td>
</tr>
<tr>
<td></td>
<td>or material damage only</td>
</tr>
<tr>
<td>Environment</td>
<td>changes in fuel consumption and emissions of CO₂, due to direct traffic</td>
</tr>
<tr>
<td></td>
<td>efficiency effects and due to changes in accident related congestion.</td>
</tr>
</tbody>
</table>

The FOT data provide some of the indicators directly; others have to be derived through additional analysis. In order to ensure consistency and comparability, it is necessary to use a common methodology at the various sites. Such a methodology does not exist yet. It would consist of a chain of analysis steps, starting with the FOT data and leading to the impact indicators needed for the CBA. Parts of the chain are available but need to be connected in a consistent way. Some parts are missing and therefore need to be developed within the project. The most important one is the step from surrogate safety measures to safety indicators. This will be explained in more detail below.

4.2 Impact assessment and scaling up of FOT data

The FOT is a source for rich, objective data on the behaviour of drivers with or without ITS functions. It is the basis for the impact assessment. However, the data does not directly provide
the impact indicators of Table 1. For example, the FOT will not directly provide savings in number of fatalities or give results for higher penetration rates. Therefore, an analysis methodology is needed to transform the FOT data into the impact indicators. For efficiency and environment, it is fairly straightforward to set up this methodology [6]. For safety, this is more challenging, and a number of approaches will be discussed in section 4.3.

For all aspects, there is the challenge of scaling up, that is, translating the FOT outcomes into results for higher penetration rates. It has to be considered that the fleet of FOT vehicles constitutes only a very minor part of the vehicle fleet on the road. For some functions, the effects may be different for higher penetration rates (and denser traffic) – this is the case, if the equipped vehicles influence the driving behaviour of other vehicles. For example, an SRS equipped vehicle may influence the speed of vehicles driving behind it. Traffic simulation will be used to analyse such interactions and study the impacts at higher penetration rates.

This means that the assessment methodology will employ two analysis routes: a direct route, where the impacts are determined directly from the FOT data, and a modelling route, where the FOT data are fed into traffic simulation tools and the impacts are derived from these tools. For more information, see [6] and [7].

4.3 Translation of surrogate measures into accident reduction potential

Several of the tested functions are safety related. Therefore, the assessment of the safety impacts is an important component of the overall assessment. It is also the most challenging component, because there is a gap between the data that will be provided by the FOT and the safety impact indicators we are aiming to obtain. This is because the FOT data will yield surrogate safety measures such as time headway (THW) or time to collision (TTC), while the needed indicators describe changes in the number of fatalities, injuries and property damage. The literature provides several methods dealing with obtaining safety impacts. See for instance the methods developed in AIDE [8], eIMPACT [9] and TRACE [10].

However, none of these methods is fully suited to be used on FOT data. In some cases, this is because the method used different types of data, in other cases it is because no consensus was reached about the relationship between surrogate safety measures and the expected changes in the number of fatalities, injuries etc. Therefore, we are currently elaborating such a method. The approaches we are investigating are:

- a method based on a physical model of relevant collision types (e.g., rear end collisions, side-by-side collisions etc.)
- an incident based approach. The FOT data can give us insight into the ratio between the number of incidents and the number of accidents with fatalities, injuries etc.
- a risk matrix approach, which defines a change in accident risk for a limited number of categories of risk parameters. For instance, the accident risk at low time headways relative to the average accident risk. The FOT data can be used to analyse the share of low time headways in the base case and the case where the function assists the driver.

In the end, parts of these approaches may be combined into a final euroFOT approach. One option is to use a physical model to fill in the risk matrix.

5. Conclusion

Within the euroFOT project, the impact on driver behaviour, performance and safety of eight advanced driver assistance systems will be assessed using a range of analysis techniques and
tools. The principal data analysis activities will include impact assessment, assessment of user acceptance and usability and socio-economic cost benefit analysis. The data analysis plan that has been developed in SP6 of the euroFOT project will provide a comprehensive and coordinated approach to the analysis of the FOT data, from data acquisition through to impact assessment. To our knowledge, it is the first such plan to have been developed in systematically guiding the analysis of FOT data.

We have identified in this paper some of the key challenges involved in implementing the data analysis plan. For a large-scale analysis activity of this kind, one of the most significant and time-consuming challenges will be the development of purpose-specific analysis methods and tools that suit the particular requirements of the FOT. The development of a common questionnaire for the collection of self-reported data and the development of techniques for the up-scaling of impact data to determine societal impacts of the functions under study are cases in point. The contribution of this project will hence lie not only in the provision of new knowledge, but in the provision of new methods and tools for the analysis of FOT data that can be utilised in future FOTs.

6. References

8. Bekiaris, E., Portouli, E., Papakostopoulos, V., et al. (2004), ‘Combining workload and behavioural effects into overall risk reduction estimate’, AIDE deliverable D2.3.3