SAFETY ANALYSIS METHOD FOR ASSESSING THE IMPACTS OF ADVANCED DRIVER ASSISTANCE SYSTEMS WITHIN THE EUROPEAN LARGE SCALE FIELD TEST "EUROFOT"

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ABSTRACT

Within the large scale field operational test (FOT) "euroFOT" an impact assessment of advanced driver assistance systems (ADAS) is conducted. Altogether, about 1000 vehicles equipped with eight different ADAS technologies will take part in the field operational test. The focus of the analysis is an impact assessment on safety, traffic efficiency and environment. This paper will present the elaborated methodologies for conducting the safety impact assessment by means of the collected data from the field test.

The safety analysis represents the most challenging part of the impact assessment, because no standardized methodologies exist. The objective of the safety analysis is to determine the change in accident risk, while driving with the ADAS functionality. Altogether two approaches have been defined for the safety impact analysis and adapted to the specific conditions in euroFOT, the event based analysis (EBA) and the aggregation based analysis (ABA). The EBA approach is applied for functions, which intend to reduce the frequency of particular time discrete events (e.g. number of unintended lane crossings). Whereas the ABA is applied for functions that change certain driver performance measures over time (e.g. distance behaviour). The necessary safety indicators cannot be determined directly from the objective data, but need to be derived by means of surrogate measures. This paper discusses the challenges for performing a safety analysis and the methodology defined within the euroFOT project to perform this analysis.

Keywords: Safety impact assessment, field operational test, benefit analysis

INTRODUCTION

euroFOT intends to analyze the efficiency of ADAS that are already present in the market or are sufficiently mature enough to be tested as commercial systems. Based on the

recommendations on existing roadmaps and on the availability of well developed systems, the following group of eight systems has been selected for euroFOT:

1. Longitudinal systems: Adaptive Cruise Control (ACC), Forward Collision Warning (FCW) and Speed Regulation System (SRS)
2. Lateral systems: Lane Departure Warning (LDW), Impairment Warning (IW) and Blind Spot Information System (BLIS)
3. Advanced applications: Curve Speed Warning (CSW), Fuel Efficiency Advisory (FEA) and Safe Human-Machine Interaction (SafeHMI)

These functions will be evaluated in different vehicles supplied by different European manufacturers. Different data acquisition systems installed into the vehicles will be used to collect a wide range of data (CAN-data, video, GPS location, etc.). The FOT is being carried out at various test sites across four European countries (Sweden, Germany, France and Italy).

IMPACT ASSESSMENT

euroFOT includes various impacts assessments, for example of traffic efficiency, environmental effects, user acceptance and other user-related-aspects, as well as safety impact assessment. The main objectives of the impact assessment are:

- to analyse the effects on EU level for the ADAS 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 in the trips made by the equipped fleets in the FOT to the EU level. This basically means scaling up effects found in the FOT data, for certain situations or for certain groups of drivers. This leads to an understanding of the effects of ADAS if they would be used in entire Europe.

Several of the tested ADAS are safety related. The assessment of the safety impacts is an important component of the overall assessment. The focus of this paper is on the methodology that will be used to perform this assessment in euroFOT. While the FOT provides objective as well as subjective data on driver behaviour with and without the evaluated ADAS, this data does not directly provide the necessary indicators for a complete safety impact assessment. Since there will be very few crashes (if any) in the FOT, it cannot directly provide numbers on fatality reductions or results for higher penetration rates. An analysis methodology is needed to transform the FOT data into impact indicators. For efficiency and environment, it is fairly straightforward to set up this methodology [1]. For safety this is more challenging, because no standardized methodology is known. Moreover the mentioned gap between the data that will be provided by the FOT and the required safety impact indicators needs to be closed.

The required safety impacts need be derived by means of surrogate measures such as to which extent the frequency of near crashes is reduced by ADAS presence, to which extent a safety margin measure like time-headway (THW) is increased by ADAS presence etc. Changes of these surrogate measures will then be translated into an expected change in the number of fatalities, injuries and property damage as a function of ADAS presence, by applying the ADAS induced changes on relevant crash statistics. For this aspect several safety related hypotheses have been defined (e.g. ACC decreases the number of forward incidents). In general safety related hypotheses are focused on the number of crashes, number

of incident events, number of hard braking events, change in THW, change in time-to-collision (TTC), change in average speed etc.. These hypotheses will be tested under different environmental conditions (e.g. road type, weather conditions, traffic density etc.) and will be used as an input for the safety impact assessment.

While literature provides several examples of methods dealing with obtaining safety impacts, e.g. the methods developed in AIDE [2] and eIMPACT [3], none of these methods is fully suited to be used on FOT data. These approaches are mainly based on the derivation of the accident risk by means of surrogate measures, such as average speed or speed limit violations. The risks are partly determined by means of subjective data, because no objective data was available. Moreover for some surrogate measure no consensus was reached about the relationship between surrogate safety measures and the expected changes in the number of fatalities, injuries etc, e.g. impact of speed on accident risk. In some cases these methods are not applicable because different types of data have been used. Within euroFOT a suited safety impact methodology has been elaborated, which is described in the following.

SAFETY IMPACT ASSESSMENT IN EUROFOT

The goal of the safety impact assessment in euroFOT is to provide an estimate of the potential safety impact each ADAS could have, if installed in a wider fleet of vehicles on the road. The term "safety impact" is here intended along the lines of an ADAS impact in terms of expected changes in crash numbers and associated injuries/fatalities. The components of the assessment are described in Figure 1 below. The starting point is to define the target crash population, i.e. the set of crashes which the ADAS is intended to prevent. Next, the FOT data is analysed by means of Event Based Analysis (EBA) and/or Aggregation Based Analysis (ABA) in order to determine whether the presence of the ADAS significantly impacts any safety related measures. Finally, any identified impact needs to be interpreted in terms of how the target crash population could be expected to change if the ADAS was widely deployed.
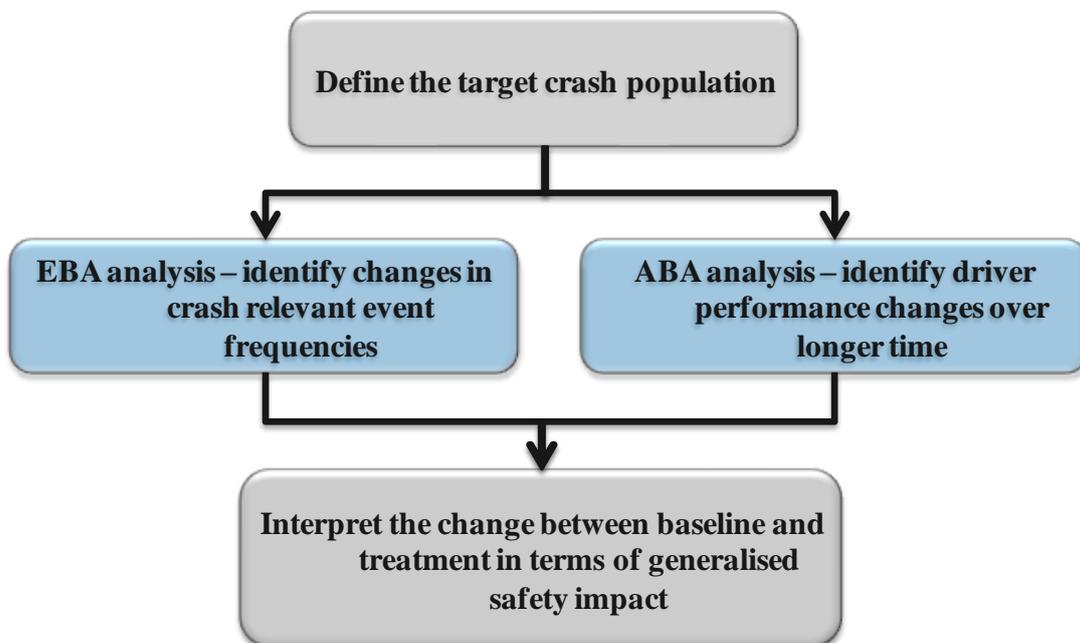

Figure 1. The three steps of safety impact assessment in euroFOT

In the following, these steps will be described in more detail, followed by example illustrations of how the procedure can be applied.

DEFINING THE TARGET CRASH POPULATION

The first part of the benefit analysis is fairly straightforward, and involves defining the target crash population, i.e. the set of crashes which a particular function is intended[1] to, and capable of, preventing. For example, for Forward Collision Warning (FCW) this is the set of rear end crashes which occur within the function's operational scope (certain ego vehicle speeds and approaching speeds to lead vehicle). For Lane departure warning, this is the set of crashes which start with an unintentional lane departure, and again, which are within the function's operational scope (visible lane markers, above certain ego vehicle speed, etc.).

Once the target crashes have been identified, data describing the crash circumstances should be cross tabulated in order to identify the most typical conditions under which these crashes occur. The intention of this step is to provide a filter, or set of limitations, in the analysis of the actual FOT data. In principle, any ADAS driven change which occurs outside this envelope of crash typical circumstances will not affects the safety impact (since by definition no relevant crashes occur outside those conditions). Thus omitting that data portion for the analysis saves time and effort, as well as focuses the analysis.

To provide the best fit with FOT data, the data source used for defining the target population should typically be a national crash database covering the country or countries where the function is being evaluated. It should be stressed that some modifications to the crash types used for that country/countries probably will be necessary, as the crash typology used to extract relevant crashes needs to be comparable to those used in other similar national databases (if not, the up-scaling of potential impact to the European level becomes a very difficult task).

In euroFOT, the identification of the target crash population will be based on the work of many previous and ongoing projects which already have addressed this issue from various angles. In particular, it is foreseen that the crash typology developed in the ASSESS project [4] will provide a good starting point, at least for cars. The ASSESS typology has the advantage that it is set up to select crashes uniformly in Swedish, British and German crash data, which matches the countries where many of the euroFOT ADAS are being evaluated. Moreover ASSESS provide an estimate of the costs and injuries associated with each crash type. In principle the ASSESS work can be used as the basis for projecting any identified crash risk changes due to ADAS presence onto injuries (including fatalities) and economical costs.

IDENTIFYING CHANGES IN SAFETY RELATED MEASURES BETWEEN BASELINE AND TREATMENT

The second part of the methodology is quantifying the impact of the presence of an ADAS, i.e. quantifying any changes in crash risk between baseline (no ADAS) and treatment (ADAS present). It is important to recognize that the number of actual crashes occurring during euroFOT is small. Basically, even when hundreds of drivers are being observed during a full year, the statistical likelihood of a crash occurring is low. This means that the simplest and

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[1] Intended is here to be understood as the set of crashes that function developers intend the system to address. While there also may be unintended effects of a safety system of either positive or negative nature, the evaluation of these is given a lower priority and will be carried out only once the intended effects are assessed given that resources for such work is still available.

most direct measure of change in crash risk, i.e. the number of crashes which occur with and without the ADAS, is not available, at least not in sufficient numbers to reliably quantify a difference between baseline and treatment. Instead, other indicators of change in crash risk have to be defined and used, such as the frequency of safety critical events or changes in driver behaviour that are known to be crash causation related. In other words, to determine whether a particular ADAS is successful in preventing a certain crash type, one must first develop an understanding of why that crash type occurs. Once that understanding is in place, a measure of change that captures the function's impact on that particular crash causation mechanism can be defined.

For example, many rear end crashes are thought to occur due to unexpected lead vehicle braking while the driver is visually distracted from the forward roadway [5]. In relation to this crash causation mechanism, a FCW system can be understood as a tool for interrupting the driver's state of distraction and alerting him/her to the braking of the lead vehicle. If FCW is successful in this regard, one would expect among other things a decrease in the number of panic braking events[2] for drivers of vehicles equipped with FCW. The frequency of panic braking events can therefore be used as an indicator of change in crash risk due to the presence of FCW.

Another way of getting at the same crash causation mechanism of unexpected lead vehicle braking events is to increase the available safety margins, thus making sure the driver has sufficient time for detection and action once the lead vehicle brakes. This is the intended function of Adaptive Cruise Control (ACC), which when activated (and within certain limits) precisely regulates the distance to the lead vehicle. By operating in this manner, ACC is intended to help the driver avoid the risk of inadvertently ending up in a situation where s/he is following close to a lead vehicle that may brake and being distracted at the same time (i.e. ACC negates the close car following aspect of the problem). To evaluate whether ACC is successful in increasing the safety margin this way, another measure of change than the frequency of panic braking is required, such as whether there is a change in average following distance, or the total driving time spent at time headways below one second.

Considering these examples, it is obvious that not only the measures used to evaluate each ADAS needs to be chosen very carefully, but also caution must be applied when summing up the benefits of multiple ADAS (e.g. ACC and FCW) present in a single vehicle. The risk of inflating the safety impact assessment by double counting effects of two ADAS addressing the same crash type is apparent. A proposal for dealing with this issue is presented below.

Two types of analysis

As the examples above illustrate, the assessment of which impact the euroFOT functions may have require two general analysis types for identifying changes between baseline and treatment, depending on which function is being analysed and how its influence on crash causation mechanisms is conceived.

The first can be called **Events based analysis (EBA).** The basic principle of EBA in a FOT context is to identify time segments (events) thought to be predictive of crash involvement, and then compare the frequency of these in baseline (where no ADAS is present) and treatment (where an ADAS is present). Examples of events include situations where the

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[2] Panic braking can be defined in many ways. While Dingus et al (2006) found that brake force alone was not a useful predictor of critical situation involvement, a more targeted definition which more directly addresses the causation mechanism at hand could be offered, such as sustained braking events with high brake force, a large lowering of delta V, and where the driver was not looking at the lead vehicle when it started to brake.

driver performs a violent evasive manoeuvre [5], i.e. where the distance in time and/or space from an actual crash is very small. These events can be identified retrospectively in the driving data, together with interaction/confounding factors such as road type, speed limit, traffic conditions, other systems etc., and then either analysed directly, or studied by for example implementing a simulation in which the events are further varied to explore potential outcomes.

EBA analysis applies primarily to ADAS which are intended to reduce the frequency of certain time discrete events directly related to loss of control, such as crashing into a lead vehicle (FCW), unintended lane departure (LDW) and commencing a lane change when the adjacent lane is not empty (BLIS). It can also be applied to events more indirectly related to loss of control, such as deciding to continue to drive when driving capacity is severely degraded (IW) and various forms of speed selection (Speed regulation systems (SRS) or Curve Speed Warning (CSW)). As long as the ADAS influence on driver performance can be described using the occurrence of discrete events, EBA analysis is applicable. Examples of previous studies where EBA analysis has been applied are discussed in [5], [8], [9], [12.

The second general type of analysis can be called **Aggregation based analysis (ABA).** This is a process for defining the change between baseline and treatment in terms of how driving performance changes over longer periods of time, such as the expected average increase in following distances for ACC in the example above, or a general decrease in travel speed for drivers with SRS systems.

The basic principle of ABA is to identify differences between baseline and treatment in driver performance measures that are aggregated over longer time segments, such as changes in average time-headway or mean travel speed, and then relate these changes to changes to crash and/or injury/fatality risk. It follows that ABA analysis applies primarily to functions which are intended to change certain driver performance measures over time, such as fuel consumption (FEA), lead vehicle following distances (ACC), speed selection for curves (CSW) or speed selection in general (SL/CC). Again, the selection of measures has to reflect ideas on underlying accident causation mechanisms, and in what way a change in the aggregate performance measure is predictive of a change in actual crash/injury risk.

Note that EBA and ABA are complementary or synergistic forms of analysis for exploring the impact on safety of a particular ADAS. For example, while a potential increase in average time headway is best investigated with an ABA analysis, a potential decrease in the number of lead vehicle conflicts is best investigated with an EBA type of analysis. However, if both types of analysis are performed on the same ADAS, it is important to remember not to unconditionally sum these effects, as they presumably reflect changes in the same underlying causation mechanism.

Interpreting what the change between baseline and treatment means in terms of a generalised safety impact

The third part of the methodology is taking the quantified differences between baseline and treatment back to the target crash population, and calculating what the identified change would mean in terms of reducing that population. This part has two steps. The first is to decide which of the identified differences are to be used for the actual prediction, and the second is to calculate the reduction in crashes. Regarding the first step, one would ideally select and compare only events and/or aggregate measures which are known to be predictive of actual crash involvement, i.e. where it is legitimate to infer that a particular change in what is measured corresponds to a particular change in crash frequency.

Unfortunately, such established relationships are yet not fully established, at least not for FOT data. For example, in terms of events, while hard braking may seem a plausible candidate for event selection, in the VTTI 100 car study [5] they were not able to reliably identify near-crash events in lead vehicle following situations based on hard braking alone, i.e. such braking occurred also in many driving situations which they did not think were indicative of crash risk. Similarly but in terms of aggregate measures, while a reduction in mean speed could be indicative of a reduction in crash involvement, there is no empirical base available for estimating the importance of mean vehicle speed in FOT data in relation to crash involvement. The currently most well developed basis is the power model proposed by [17], where a relation between some speed parameter (usually mean speed) and accident severity is inferred. However, that model relates mainly to speed choice on highways and rural roads in free flow conditions, and the empirical basis comes from cross-sectional data measured on selected road sections rather than from mean speeds as chosen by an individual driver across all possible driving conditions. The applicability of the model on FOT data therefore yet has to be validated (for an excellent discussion, see [18]).

It follows that insight into crash causation mechanisms is the key both to the selection of relevant measures of change between baseline and treatment, as well as for interpretation of what those changes mean, in terms of how the target crash population may change if the evaluated ADAS is introduced on a larger scale in the vehicle fleet. Here, while the euroFOT effort naturally is guided by the numerous previous projects in the area (see for example [5] and [8-13]), and also expect to make its own contribution in terms of uncovering details on how driver behaviour relates to crash involvement, it should be kept in mind that crash causation still is a topic at the initial stages of exploration. For most measures, the estimates of safety impact will therefore lean toward the conservative.

If a difference between baseline and treatment has been established for an ADAS in terms of a risk indicator (e.g. in the frequency of safety related events or mean travel speed), the final step is the interpretation of this difference in the risk indicator in terms of change in the target crash population. This calculation can be done at various levels of detail. The simplest solution is to apply the identified change to the target population as a whole. For example, if the frequency of FCW relevant near crashes is 20% lower in the treatment phase, this could be used to predict a 20 % decrease in FCW relevant crashes and injuries if all vehicles were equipped with the system. A more sophisticated approach, but which also requires a larger data set, is to calculate the induced change and its relative impact for individual levels within the typical crash conditions before summing up. For example, if there are 2000 rural and 3000 urban FCW relevant crashes, and the near crash reduction ratio is 17 % for rural and 25 % for urban environments, the potential decrease in crashes would be (0.17*2000 + 0.25*3000)/ 5000 = 21.8 %.

This type of sophistication can also be extended to the injury calculations. For example, rather than assuming a general decrease in injuries and fatalities, it may be possible to assign severity levels based on for example the posted speeds under which the crashes in the target crash population occur (i.e. a higher posted speed generally implies higher initial vehicle speeds, and thus more severe injuries). Given that this holds, a 15 % reduction in near crashes would predict a higher injury prevention at the 90 km/h level than the 50 km/h level.

Example of Events Based Analysis (EBA)

To illustrate the process described above, an applied example of EBA analysis for a Forward Collision Warning / Adaptive Cruise Control system deployed in Sweden is described below.

1) Selecting a target crash population – Volvo Cars are evaluating a FCW/ACC system in the Gothenburg area of Sweden, and this example will be based on the initial data that has been collected from those drivers. The data set consists of 8000 hours of driving, of which 4549 hours were in baseline and 3920 in treatment. As this comprises only about 10% of all the data that will be collected, it has to be stressed that this example is very tentative, and all numbers (except the size of the target crash population of course) will be subject to revision once the full dataset has been collected.

To select a relevant crash population, data from STRADA was used. STRADA is a publicly available database that contains all police reported and most hospital reported traffic accidents that occur in Sweden. In order to find a relevant target population, , data from the years 2005 to 2008 was compiled for analysis. From the total set, a slightly modified version of the ASSESS crash type described above was used to select relevant crashes. This included all passenger car crashes where the two vehicles were travelling in the same lane and direction when the front of one vehicle struck the rear of the other vehicle. The original ASSESS type was extended to also include situations when the car strikes a vehicle that is waiting to turn or turning (as these otherwise would be subsumed under the intersection crash type in ASSESS). The annual Swedish averages, cross-tabulated for the most important traffic environment conditions, are shown below in Table 1.

Annual average of FCW relevant crashes for cars in STRADA 2005-2008			Posted speed (kph)					Total
			30	50	70	90	110	
Urban	In junction	Dry	9	291	57	5	1	1497
		Not dry	5	174	47	5	1	
	Outside junction	Dry	15	361	156	32	9	
		Not dry	9	192	91	32	8	
Rural	In junction	Dry	1	39	86	77	7	1187
		Not dry	0	25	49	37	8	
	Outside junction	Dry	2	36	153	161	130	
		Not dry	1	17	87	124	150	

Table 1. Estimated annual average accident frequencies for FCW / ACC relevant crashes in longitudinal traffic for Sweden, based on STRADA data collected in 2005-2008. Highlighted cells represent ~92 % of all crashes.

Identifying change between baseline and treatment –In this step, a pool of crash relevant events were selected from the driving data by successive filtering steps. In order to find an initial set of events to apply the filters on, the simplest solution possible was used, i.e. the warnings provided by FCW were used to flag events. Next, these events were filtered in order to single out what could be called "true" near crash events (there were no actual crashes in this data sample), i.e. events where a real crash was more or less imminent and where the driver can be expected to have benefited from being alerted to this fact by the ADAS when in the vehicle.

As can be seen above in Table 1, very few crashes occur at speed limits below 50 km/h. Thus, first fall events occurring at posted speeds below 50 km/h were taken away. Next, all events where the driver already had started to brake when the warning was given were excluded, on the assumption that getting a warning in that situation does not affect situation outcome. Last, all events where the maximum brake pressure during the event was at least 10 % of the highest brake pressures logged (thus excluding soft braking events), and where time-to-collision (TTC) at max brake pressure was less than 1 second (i.e. where the vehicles were close in time to colliding before the driver was comfortable with starting to release the brake

pedal). These successive filters resulted in an outcome of 12 events, of which 8 occurred in baseline and 4 in treatment (note that other types of filters than those used here might be more relevant for the final analysis).

3) Interpreting what the change between baseline and treatment means − The final step is to interpret this difference between baseline and treatment in terms of influence on the target crash population. First, there is the issue of size and significance of an identified difference. To test this, many different methods described in [6] are available. The simplest form of comparison is to make a contingency table by counting the frequency of events in baseline and treatment conditions (based on some form of exposure normalisation, such as the number of events per driving hour) for each driver to understand, whether ADAS presence causes a change in event frequency. The risk change due to system presence can then be quantified and statistically tested using both relative risk (RR) $\Pi 1 / \Pi 2$ and/or the odds ratio (OR) $(\Pi 1 / (1-\Pi 1))/(\Pi 2 / (1-\Pi 2))$. It has been shown that OR approximates RR when $\Pi 1$ and $\Pi 2$ are small.

In Table 2 below, this has been illustrated for the example data. However, as this example represents only a small portion of what will be the final dataset, the significance testing not performed to avoid confusion with later results.

	Baseline (system "off")	Treatment (system "on")
Number of crashes (or safety events)	8	4
Km's driven (or duration)	4549	3920
Crash (or events) rate	0,00176	0,00102
Odds ratio		**0,579**
Relative Risk (RR)		**0,580**

Table 2. Contingency table for events in baseline and treatment

Now, if the numbers in Table 2 were taken at face value, it seems like the relative risk of experiencing a near crash relevant for driver with ACC/FCW is reduced with over 40 %, compared to not having that ADAS in the vehicle. Linearly extrapolated to the annual average of 2685 FCW relevant crashes in Sweden each year (see Table 1 above), that would mean a reduction of over 1100 crashes annually (600 ~in urban areas and 500 in rural). Of course, as this number comes from a limited dataset which has not been checked for consistency and biases, it only serves as an example and not as any type of prediction.

In terms of the methodology, a drawback of contingency tables is that it is only possible to consider one factor at a time, and interaction/confounding effects cannot be addressed. Furthermore, contingency tables assume that observations are independent of each other, an assumption which does not suit FOT data very well, as it will contain unavoidable driver-specific correlations (i.e. some drivers will experience more events than others).

To study interacting/confounding factors and to account for these driver specific correlations, more sophisticated statistical models need to be applied. These models are generalizations of the linear models which have been adapted to a binary outcome, something which suits the EBA analysis division of events into baseline and treatment events well. These models include additional parameters to deal with correlations, and confounding factors are regarded as explicative variables that can be used to predict event probability.

One such model is the "Generalized Estimated Equations" (GEE) model, originally developed to model longitudinal data by Liang and Zeger [7], which assumes that

observations are marginally correlated. Another such model is "Generalized Linear Mixed Models" (GLMM). Similar to the GEE model, GLMM assumes correlated observations for the same driver. In addition, GLMM also assumes that there is a random effect associated with each individual driver (i.e. one driver can be associated with higher and another with lower risk of event involvement). This has the additional advantage of allowing to control for a small population of drivers being involved in a large proportion of safety events, something which indeed may become an issue [5]. Both GEE and GLMM models can also accommodate multiple risk factors, which allow those factors to be evaluated simultaneously. Indeed, this capability may also be used to evaluate different systems in use at the same time or at different times but with possible interactions. For the final dataset, these or similar more complex models will be applied where appropriate, depending on the system tested and the events analyzed. For a more technical and detailed description, see [6] and [7].

Example of Aggregation Based Analysis (ABA)

A type of ABA analysis that is being developed in euroFOT combines time continuous changes in car following states of the vehicle (and driver behaviour) between baseline and treatment with computer simulation of lead vehicle conflicts. It estimates the number of accidents as the product of *accident probability*, *accident severity* and *exposure*, following established practice [16]. The first two factors together are called *accident risk*. The method can be seen as an adaptation of existing methods. In euroFOT this method will be applied to the functions ACC and SRS. Additional requirements on this method are the usability without video data, because most of the euroFOT vehicles do not have video data. Moreover it should be usable without in-depth accident statistics, because on the EU level there is only a high level accident database and it should run (almost) automatically after initial preparation. The latter requirement is motivated by the huge amount of data being produced in euroFOT which makes an interactive form of analysis practically impossible. Another motivation is that due to the size of project, the experts working with the data are typically not the safety experts involved in modeling safety impacts. The assessment method is set up such that users of the method merely need to provide the kilometers driven under various circumstances, from which the safety impact is determined automatically.

The method assesses changes in potential crash involvement by sampling distributions of lead and following vehicle speeds and accelerations with ACC off and on from the FOT data, and then populating the starting conditions of the simulated conflict through random sampling from these distributions. In this way, a large variety of possible conflict outcomes can be explored, and it can be assessed whether those outcomes (in particular, the number or virtual crashes) differ significantly, if the starting conditions are sampled from treatment (ACC on) rather than baseline conditions (ACC off). The simulation applies a physical model with speeds, accelerations, distance-headway (DHW) and driver reaction time as input.

This approach is developed for rear-end accidents only. Initial testing has been conducted using a limited data set. Though the results do not have sufficient statistical power for drawing conclusions (due to the small data set), they seem to be reasonably in line with expectations. Additional testing is being performed with a larger data set, including sensitivity analysis and validation with crash statistics. The first results do show that the risk matrix approach is applicable to rear-end crashes. To apply it to other accident types, the relation between the risk indicator (e.g. impact speed) and the severity of the accidents need to be better understood.

Note that the EBA and ABA are complementary forms of analysis and should be applied according to the way the evaluated ADAS is intended to influence crash risk (i.e. the

proposed causation mechanisms that the ADAS is intended to avert/mitigate). For some systems, both EBA and ABA analysis may be applicable, e.g. ACC maybe hypothesised to induce both changes in average time headway as well as changes in the frequency of hard braking events. However, if this is the case, it is important to remember not to unconditionally sum these effects, as they presumably reflect changes in the same underlying causation mechanism (more on this below). As a consequence additional mechanisms are considered in the euroFOT project to avoid handle this risk.

WHAT IF TWO OR MORE ADAS ADDRESS THE SAME CRASH TYPE?

If three different ADAS target the same crash type, it follows logically that their combined effect cannot exceed a 100 % crash reduction for that type. This simple reasoning points to the necessity of making a holistic and/or sequential type of calculation when considering the benefit of two or more ADAS addressing the same crash type.

One relatively simple, yet robust way of handling this problem is by positioning the ADAS in question along a timeline, or event line, where the ADAS which is farthest removed from the actual critical event is assessed first, and any impact that ADAS has is used to reduce the target crash population which comes next in the event line.

A hypothetical example is provided below in Table 2, where the potential benefit of fitting a single vehicle with eight different safety functions is estimated. The example starts from a total crash population of 100 000 crashes, and as can be seen to the bottom right; once the effect of all eight systems has been identified for there are still 18440 crashes that remain unaddressed. Or put reversely, the combined effect of the eight systems is estimated to $100.000 - 18.440 = 81.560$ crashes, i.e. an approximate total prevention estimate of 81.6%.

As stated, this approach is very linear in nature, and more complex real world dependencies may of course exist. For euroFOT however, an initial step would be to adapt a similar holistic model for the impact of certain functions. For example, ACC and FCW both mainly address the crash type 6a from ASSESS - Accidents in longitudinal traffic – same direction [4], and for technical reasons, very few vehicles exist which have one but not the other (as they use the same type of sensing). It would therefore be recommendable to assess those together in terms of their influence on the ASSESS crash type, to avoid any double counting. For this, the FCW benefit calculation should in principle only be performed on the crash population that is left after the ACC benefit has been estimated, in order to avoid double counting (i.e. a crash cannot be prevented twice).

Drawing a time line or phase diagram of the developing critical scenario (as for the road departure scenario in Table 2), and then reasoning about in which phase each function is active, partially resolves the issue of benefit calculation for multiple functions addressing the same crash type. However, one remaining problem is what happens when two functions address the same step of such a sequence, i.e. when their influence on particular crash type cannot be separated the sequential way.

The answer to this problem is twofold. First, an empirical solution may be available. If the same metric can be used to assess their influence, an initial step is to see whether this metric changes identically over the most relevant crash conditions. If they affect different portions of the typical crash conditions, that can be used as an indication of the functions being complementary. If they affect the same portions, this indicates that the functions indeed are redundant, and that either could be done away with without compromising the benefit.

Second, for euroFOT, this problem (at least so far) does not seem to arise. At least in relation to EBA analysis, the functions under evaluation all seem possible to place in logical steps along a projected critical timeline for their respective crash types. For example, for the Volvo

cars participating in the study, the above example covers the sequentially of IW and LDW in relation to run-off-road crashes, as well as the sequentially of ACC and FCW in relation to accidents in same direction longitudinal traffic.

Hypothetical example of scenario based holistic benefit analysis for road departure scenarios. Calculation is based on an assumption of 100.000 accidents of the same type.								
	Potential for crash reduction						**Potential for injury reduction**	
Type of performance variability leading to loss of control	Non-conflict			Conflict	Imminent crash		Crash	Post-crash
Type of performance variability leading to loss of control	Neglect of safety zone boundary	Reduced awareness of safety zone boundary	Reduced lane tracking performance	Temporary attention allocation to non-driving related task	Over-correction	Non optimized use of brake capacity		
Contribution factors in crash investigation	Driving while under influence	Fatigue & low vigiliance	In-vehicle or outside vehicle distraction	Observation missed (leaving lane)	Excessive steering	High speed vs. another vehicle	Rollover	Long time to reduce
Active systems addressing these factors	Alcolock	Fatigue Monitoring	Lane keeping support	Lane departure warning	Electronic stability control	Collision mitigation by braking	Roll over protection system	E-call function
Factors prevalence (in how large percentage of the crashes is the factor involved)	50%	50%	75%	75%	25%	25%	37.5%	12.5%
Estimated systems efficiency (percentage of drivers interacting correctly with the system)	30%	30%	30%	30%	30%	100%	80%	100%
Crashes mitigated	15000	12750	16256	12599	3255	10035	9032	2634
Crashes left to address	85000	72250	55994	43395	40141	30105	21074	18440

Table 3. Impact of multiple safety functions addressing a single crash type

The final system being evaluated by Volvo cars, i.e. BLIS, is primarily intended for a specific crash type related to lane changes. While this on the kinematic level overlaps with situations in which LDW also would activate, the underlying mechanisms, and the driving conditions under which they typically occur, are most likely fundamentally different. While BLIS addresses under informed but intentional lane changes in a multiple lane, dense traffic environment, LDW is intended to address unintended lane departures in low workload driving conditions.

WHAT IF AN ADAS INFLUENCE OTHER CRASH TYPES THAN INTENDED?

In the discussion of how to identify the target crash population above, the idea is to select crashes which the ADAS is intended to address, which here is to be understood along the lines of design intent, i.e. the type of crashes which the ADAS designers foresaw as the main beneficiary of the ADAS, and which the ADAS therefore has been developed and tuned for. For example, for FCW this is the set of rear end crashes which occur within the function's operational scope (certain ego vehicle speeds and closing speeds to lead vehicle). For Lane departure warning, this is the set of crashes which start with an unintentional lane departure, and again, which are within the function's operational scope (visible lane markers, above certain ego vehicle speed etc).

However, an often raised worry concerns what is referred to as unintended side effects. While an unintended effect can be of either positive or negative nature, there is a concern that the presence of one ADAS may lead to an increase in non-intended crash types, i.e. crash types not directly related to the function. A hypothetical example would be FCW presence leading the driver to trust the FCW to alert him/her to forward critical events, in which case lateral control may decrease as a side effect of reduced driver attention to the primary driving task.

If this occurs, FCW presence may lead to an unintended increase in the number of inadvertent lane departures.

This concern actually can only be addressed on an empirical basis. In principle, for something like this to happen, some form of mediating mechanism must exist (such as the decrease in lateral control in the example above). If such a mechanism does indeed exist, its nature and influence can be hypothesized about and its influence can be tested for. For the above example, this would consist of looking at e.g. the standard deviation of lane position for FCW on and FCW off conditions, with LDW on/off as a control factor.

WHAT IF ONE ADAS INFLUENCES THE EFFICIENCY OF ANOTHER?

Another often raised worry concerns potential function interaction, i.e. that the presence of one function will influence the effect of another function. Paraphrasing the hypothetical example above, if FCW presence leads to a reduction in lateral control as a side effect of reduced driver attention to the primary driving task, the number of lane exceedences, and associated Lane Departure Warnings given, would presumably be higher for a driver with FCW than for a driver without.

On the empirical side, this is relatively easy to test for. As long as there is sufficient data in the treatment and baseline conditions, the frequency of LDW's given with FCW present compared to when in baseline, or the frequency of FCW's in ACC on and ACC off conditions, etc, be counted, normalized for exposure and then compared.

On the theoretical side, the implications of any differences found are less easy to determine. Ljung et al [14] found that drivers with previous exposure to LDW to a larger extent responded correctly to a FCW in an unexpected lead vehicle braking event, compared to drivers who did not interact with any ADAS prior to the event. On the other hand, in one of the on road studies performed under the AIDE project, FCW and LDW received positive ratings for usefulness and satisfaction when used separately. However, having both in the vehicle at the same time led drivers to rate LDW negative in terms of satisfaction and FCW negative in terms of usefulness [15]. In other words, the issue is multidimensional and plenty of more work is necessary to find a suitable solution.

SUMMARY

In this paper the approach for conducting a safety impact analysis by means of the data collected within euroFOT project is described. The defined approach in euroFOT is divided into two main steps. The event based analysis (EBA) is focused on the analysis of systems which are intended to reduce the frequency of particular time discrete events (e.g. Lane Departure Warning, Forward Collision Warning). The second method is called aggregation based analysis (ABA) and is mainly focused on systems that are intended to change certain driver performance measures over time, such as how much fuel is consumed (Fuel Efficiency Advisor (FEA)), lead vehicle following distances (Adaptive Cruise Control (ACC)) and average travel speeds (Speed Regulation System (SRS). Both methods will be tested by using collected data within the piloting phase of the euroFOT project. The data collection phase will end by beginning of June 2011. Following this phase the data analysis will start. Within the data analysis the impact assessment with respect to impacts on safety, traffic efficiency as well as environment will be conducted. The results of the impact assessment will be available by March 2012.

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