INCIDENT DETECTION BASED ON VEHICLE CAN-DATA WITHIN THE LARGE SCALE FIELD OPERATIONAL TEST “euroFOT”

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Paper Number 11-0042

ABSTRACT

The euroFOT project is the first large-scale Field Operational Test (FOT) of multiple Advanced Driver Assistance Systems (ADAS) in Europe. It will evaluate the impact of ADAS on safety, traffic efficiency, environment, driver behaviour and user acceptance in real life situations with normal drivers by means of collected data from instrumented vehicles. By offering valuable information for the short- and long-term impact of ADAS the euroFOT project aims to encourage the deployment of ADAS. Altogether, about 1000 vehicles equipped with different ADAS technologies will take part in the field operational test. The FOT is coordinated by five Vehicle Management Centers (VMC) and carried out at various operation sites across six European countries (France, Germany, Italy, Netherlands, Sweden and United Kingdom). Within this paper the approach and the requirements for implementing a reliable and automated incident detection process by means of CAN-data for assessing the impact of ADAS at the German1-VMC are presented.

INTRODUCTION

Today road transport in Europe faces enormous challenges caused by economical and social changes in the last years. These lead to new demands for each individual as well as for the entire economy. The individual demand for personal mobility and flexibility is increasing in Europe as it has already been over the last ten years. Studies show that the number of vehicles has grown from around 400 vehicles per 1000 inhabitants in 1995 to 480 in 2005 within the EU25, which caused a higher traffic density [1]. This growing number of vehicles is accompanied by an increased driver workload, due to increased traffic complexity and driving tasks. This development results in a higher accident risk. In order to support drivers and to make driving safer as well as more comfortable and efficient with respect to environment and traffic flow advanced driver assistance systems have been developed. Their potential to provide a positive impact on traffic safety and efficiency is well recognized [2].

Over the past years Anti-lock Braking Systems (ABS) or the Electronic Stability Program (ESP) as well as passive safety systems, e.g. safety belt or airbag, caused a significant reduction of accidents with injuries and especially of traffic fatalities. However there are still 35000 fatalities on European roads every year. Hence the European Commission (EC) has announced in the 2001 White Paper on transport the objective of halving the number of fatalities on European roads until 2010 [3].

Started within the seventh framework programme of the EC, the euroFOT project establishes a comprehensive, technical and socio/economic assessment programme for evaluating the impact of ADAS on safety, traffic efficiency, environment and user acceptance in real life situations. By means of instrumented vehicles data is collected and evaluated within the field operational test, in order to answer the pre-defined research questions.

German1-VMC

The fleet of the euroFOT project is coordinated by five vehicle management centers (French, German1, German2, Italian and Swedish) across several European countries. The following map presents the geographical location of the VMCs in the euroFOT project.

Figure 1. Vehicle management centers in the euroFOT project

This paper focuses on the approach defined for the German1-VMC. At the German1-VMC a fleet of 200 vehicles is managed, which consists of 60...
trucks from MAN, 100 passenger cars from Ford and 40 passenger cars from VW. The data acquisition and processing as well as data storage processes for collected data from these 200 instrumented FOT vehicles are defined and implemented by the Institut für Kraftfahrzeuge of the RWTH Aachen University (ika). The field operational test is conducted for a period of 12 months. The tested ADAS functions cover Adaptive Cruise Control (ACC), Lane Departure Warning (LDW), Forward Collision Warning (FCW) and Curve Speed Warning (CSW). The following figure provides an overview of the German1-VMC.

**Figure 2. Tested ADAS functions and fleet composition at the German1-VMC**

All 200 vehicles are equipped with Data Acquisition Systems (DAS), which allow recording and temporary storage of all relevant measured values as well as the transfer of previously recorded data to a central storage server. The estimated amount of data at the German1-VMC adds up to approximately 6 TB, considering a duration of one year for the field test. As a result of this huge amount of data a detailed analysis of the complete data within the planned period of time is not feasible. Hence a limitation of the evaluation to relevant driving events is necessary, in which the particular tested functions have an influence (e.g. car following, lane change manoeuvres, critical distance situations etc.). These events are extracted from the collected data by an automated process which has been developed at ika. The event recognition algorithm automatically detects certain patterns (combinations of different measures) in the CAN- and GPS-data. Although this approach demands high computational performance, it enables saving considerable amounts of time compared to manual processing of the large amount of data. In the following methodology, the data processing chain as well as the automated event recognition processes are presented.

**METHODOLOGY**

The relevant data to be collected within the field test has been derived from the research questions of the project. Based on these research questions (assessment of the impact of ADAS on traffic safety, traffic efficiency, environment as well as driver behaviour and acceptance) hypotheses to be tested (e.g. „ACC decreases the number of incidents“) have been defined. By means of the hypotheses the required signals and data sources have been identified. The definition process applied for the euroFOT project is presented in Figure 3.

**Figure 3. Definition process of required signals**

Depending on the vehicles used, the available signals can vary between the different vehicle types and the VMCs. Moreover the vehicle types and instrumentations are not the same at all VMCs. Some of the VMCs collect only CAN-data, while others additionally collect video data, eye glance information etc. For each operation site an adapted experimental design has been defined, in order to consider the specific basic conditions. In general the experimental design consists of a baseline (system-off period) as well as a treatment period (system-on period). At the German1-VMC the first three months of the field operational test will serve as a baseline period during which the ADAS functions will be deactivated, while data on driving performance (e.g. vehicle speed, acceleration etc.) is collected. During the following treatment period, the functions to be tested will be activated and the recording of the same driving data will be continued. Comparisons between recorded driving behaviour 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. As an example the figure below presents the experimental design for 60 trucks at the German1-VMC.

**Figure 4. Experimental design for the fleet of 60 trucks at MAN**

The trucks are equipped with ACC and LDW and are divided into two fleets. After the three month baseline period (A1) the functions will be tested separately at first. 30 trucks will have only ACC.
available while for the other 30 trucks only LDW is available. In the second treatment period (B₂) both functions will be activated and available for the drivers. By means of comparisons between relevant data sets for the same participants in the first treatment (B₁) and second period (B₂) the impact of the combination of functions (ACC and LDW) will be assessed. Both tested functions will be deactivated within the second baseline period (A₂), in order to assess potential learning effects by comparison with baseline period (A₁), due to seven month treatment period [4].

During the whole experimental phase data is collected from the instrumented vehicles. For the German1-VMC it has been decided to continuously record the required signals with defined sampling rates instead of collecting data only after detection of a relevant situation. Thereby some remarkable disadvantages can be avoided. One of the main disadvantages of a discontinuous recording of the data is a loss of possibly relevant data because of not well-suited event recognition (e.g. wrong thresholds). The detection cannot be adapted at a later stage, if relevant raw data has not been collected. At the German1-VMC the signals are recorded permanently and event recognition is applied “offline” within a server-side process. The availability of the complete raw data allows reprocessing of information after implementing any desired adaptations. However, the high amount of data that is generated compared to the situation-based approach results in higher demands on the data management.

**DATA MANAGEMENT**

For data collection in the field, the German1-VMC has equipped in total 200 vehicles with data acquisition systems (DAS). These DAS will collect data from up to four CAN-busses of the vehicles and additionally GPS-information. Other signal sources on vehicles side are not used at the German1-VMC, in order to ease the integration of the DAS into the vehicles compared to other scenarios such as integration of additional sensor equipment (e.g. video sensors).

The data measured on the connected CAN-channels will be stored in a first stage on a FLASH storage device installed on the DAS. The DAS at the German1-VMC offers the possibility to communicate with the device during operational time of the field test using an integrated GPRS module. This allows wireless uploading of recorded information to a centralized server system, while the DAS is collecting data simultaneously. Therefore the data is compressed and encrypted. By means of a GPRS connection the DAS status and operation on board of the vehicle can also be checked and monitored during the entire operation time. Figure 5 presents an overview of the process stages of the German1-VMC approach.

**Figure 5. Data acquisition and processing at the German1-VMC**

These stages are data acquisition, pre- and post-processing of data, storage and analysis of data. After the data has been uploaded to the server, further processing steps are conducted. Within these the data will be enriched with additional attributes from a digital map (e.g. road type, speed limit), which are derived by means of GPS-information. Afterwards all necessary signals for the detection of relevant events and situational variables are available. Finally the processed data as well as the initially recorded data is stored on a server. Here the raw data is stored in files on a per-trip basis as a backup for the case that a re-processing of certain data sets will be necessary. The processed data is filled in tables of an SQL-server. Data on the SQL-server will serve as basis for the evaluation. The upload procedures are designed and implemented to work fully autonomously. Autonomous operation means that no user interaction – neither on the driver side nor on the operator side – is required. Hence the drivers are totally kept out of the data retrieval loop. No training of the drivers participating in the field test is needed and the loss of data due to maloperation is excluded. Besides the event recognition and data retrieval steps the entire process chain for data management has been automated. Figure 6 presents the structure of the software architecture that has been developed at ika for this purpose.

**Figure 6. Software architecture of data management process at the German1-VMC**
The architecture for data management on the server side consists of several different software components. The coordination of the interaction between the software components is performed by the Central Management System (CMS). After data has been successfully uploaded on the server, the CMS is responsible for passing the data to the Data Manager, which subsequently manages the data processing. Data is passed between these software elements each time one process step is accomplished. The processing contains the conversion of the data to a standardized file format, the quality check and plausibility analysis as well as the enrichment and classification processes. The processed data is stored on an SQL based server at the end, in order to make the data available for the analysis. For configuration management and diagnostic purposes as well as operator access, additional software components (e.g. diagnostic processor etc.) complete the infrastructure for the automation of the whole process chain.

Data processing

All data files collected by the DAS are on a per trip basis. This means that the recording is started as soon as the vehicle’s engine is started and is completed at the latest one hour after the vehicle’s engine has been switched off. The follow-up time is applied, in order to provide additional time for data upload, which might have been not possible during the trip. If all collected data has been uploaded to the server during the trip, the DAS will be deactivated directly after the engine has been switched off. The data files are directly passed to the processing chain by the CMS as soon as an entire recording file is available on the server side. The pre-processing is designed to work on a per-trip basis, while the post-processing (on SQL-database) will build a more complete overview. The pre-processing of data can be subdivided into two main process steps:

- Generation of processed and derived data (needed for hypotheses testing).
- Quality analysis, in order to ensure reliability of the analysis.

These two processing steps are split into two software components with a similar processing structure. The Plausibility and Check Manager is responsible for analyzing the usability of signals. Thereby the main functionality is realized by several extensions, each responsible for a specific aspect of data quality analysis. Checks for missing data and check for signal ranges are considered together with wrong dynamic behaviour and incoherent behaviour of signals. The data quality checks are performed directly after the upload and after each modification of the data.

In the next processing step the available signals are used to detect relevant events as well as situational variables, in order to classify the data for focusing the analysis on relevant data sets. Furthermore the performance indicators (PI) needed for testing of the hypotheses (e.g. time headway, time to collision etc.) are calculated. For the whole process additional information is needed, which is derived from the existing signals (GPS and vehicle dynamics) by using attributes from digital maps (e.g. road type, number of lanes etc.). These processes are conducted by the Event, Enrichment and PI Manager. Each function (event recognition, PI calculation etc.) is realised as a separate extension of this software element.

Process planning

Process planning is related to the execution order and scheduling of the pre-processing functions. The increasing amount of data and the high complexity of the pre-processing chain (including the dependencies between the algorithms) become highly complicated. Thus strategies like proper automated planning of execution order and parallelization of independent execution trees are essential. This is especially of importance, if the used algorithms for the analysis evolve during the FOT. In this case the consistency of all processed data still needs to be guaranteed. This requires that already processed data can be re-processed with maintainable efforts. An entire re-calculation of an amount of 6 TB of data and an expected amount of more than 100,000 trips each time one algorithm evolves is not a reasonable approach. Therefore it is necessary to focus on only the relevant respectively affected data sets. This approach is realized by combining a petri-net graph with versioning information for algorithms and processed data.

The figure below gives an overview on how process planning is performed using the software framework developed at ika. The realized concept achieves a decoupling of algorithm implementation and execution. All algorithms are encapsulated with additional meta information. This meta information covers the required input signals for the calculation as well as the generated output signals, versioning information for detection of evolution, author, comments and annotation of the functionality, which can be used by the process supervisors. The algorithm together with these meta data is committed to the CMS software framework and embedded as extension in the algorithm pool of the framework.
EVENT RECOGNITION

The data analysis (hypothesis testing, impact assessment) will be conducted on an SQL-database. However, due to the large amount of information, the data processing on this database is not reasonable with regard to the computational efforts. Thus the data processing steps are performed before the data is stored in the database. A substantial part of the data processing is the automatic event recognition process, which detects relevant driving situations for the analysis. Besides the events recognition situational variables are detected, which provide additional information with respect to environment and the vehicle state (e.g. weather conditions, road type etc.). Depending on the manufacturer and the available signals up to 18 different events and 22 situational variables can be detected. For analysis purposes pre-defined scenarios are used to assess the impact of the tested functions.

These scenarios are mainly detected by combining events with different situational variables. This step is performed within data processing. An example for detection of relevant scenarios is presented in Figure 8. The combination of the car following event (relevant event for ACC) with different situational variables provides the scenario of a car following event under the relevant weather, traffic, lighting and road type conditions, e.g. car following on a motorway, in day light and high traffic density.

Figure 7. Process scheduling using petri-nets and versioning information

For starting the execution chain – as soon as new data is available – the CMS performs a dependency analysis based on the meta information from the algorithm pool by building a petri-net of the processes using the signal information. Thereby unresolved dependencies (e.g. missing input signals) can be identified and the order of execution determined. The execution of the processes will be performed by distributing the functions together with the required FOT data to a computation cluster.

A process for management of modifications (e.g. integration of additional or evolution of already existing algorithms) is autonomously practicable by means of the petri-net approach. As soon as new processes are registered or modified, the CMS automatically performs re-processing of all affected functions, in order to keep the data consistent. With the presented approach a fully automated data upload and processing is achieved. In the following the automated event recognition process is presented.

Figure 8. Procedural steps to cluster data for analysis purposes

For the implementation of the event recognition process three major requirements have been defined at the German1-VMC. The first requirement derives from the high amount of data that has to be processed. The processing needs to be performed in a reasonable time period, in order to have the processed data available for analysis. Thus the algorithms of the event recognition have been optimized with regard to processing time (realization of short processing time).

The second important requirement is the need for a manufacturer-independent recognition, in order to ensure the comparability of the results in the end. Since CAN signals of three different manufacturers are collected at the German1-VMC, the available signals differ between the manufacturers. Moreover the type of signal output can vary between the manufacturers. An example is the signal of the turn indicator, for which two different outputs can occur:

- One signal, which includes information on the state of both turn indicators as well as the hazard warning lights.
- Two signals, which include information on each turn indicator state.

Hence a harmonisation of the signals is essential before the event recognition can be initiated. These have to be implemented individually for each manufacturer. In a further step, required signals for the recognition process that are not available are identified and the possibility of using alternative signals is checked. For example for two manufacturers the information on the selected gear is not or only partly available.

Benmimoun 5
for vehicles with manual transmission. In this case information is obtained from the ratio of engine speed to wheel speed. Because the participating vehicles do not only differ in the manufacturer but also in their engine types, it is necessary to identify the transmission ratios according to the engine types. For this purpose the ratios occurring during a trip are registered in a histogram and afterwards classified into the different gears, considering certain given thresholds. Thus an engine independent identification of the selected gear can be achieved. However there are some signals, which cannot be derived from others. In these cases the particular event will not be considered for vehicles of the corresponding manufacturer.

The third important requirement is the quality of the automated event recognition. Relevant situations have to be identified with high precision and reliability. Especially for the German1-VMC this is important, because there is no video data available, which would enable a later verification of the detected events. Previously conducted evaluation on pilot data (collected within the piloting phase of the project) revealed a high number of false detections due to improper thresholds. The thresholds have been mainly defined based on a literature review of different previously performed FOTs, in which generally video data has been deployed. In these FOTs potential events, which have been detected by the algorithms, were finally assessed on the basis of the video data. Hence for the German1 VMC the decision has been taken to equip pilot vehicles with additional video cameras, in order to collect video data for verification purposes. Altogether approximately 40 hours of video and CAN-data have been evaluated in the piloting phase. The results were incorporated into the optimization of the automated event recognition.

The newly derived thresholds helped to significantly improve the reliability of the event recognition. However, some situations cannot be identified reliably by means of available signals and thresholds. An example is the detection of a lane change manoeuvre. For vehicles which are equipped with lane departure warning systems (LDW) the additional lane information given by the installed digital camera enables to reliably detect lane changes (provided that lane markings are available). For those vehicles which are not equipped with LDW systems two alternative solutions have been investigated. The first option is to analyze the yaw rate in combination with the state of the turn indicators. Above a vehicle speed of 80 km/h, it is checked whether the yaw rate exceeds the threshold of 0.5 °/s in a time interval of 1 second before and 5 seconds after the turn indicator has been activated. In this case a lane change is detected. This approach has two essential disadvantages. The detection depends on the usage of the turn indicator, which cannot be assumed to be used by all drivers when performing a lane change manoeuvre. Moreover the recognition can only be applied for higher speed values. However, if both conditions are fulfilled the detection is reliable.

The second approach is based on the lane change algorithm developed by [6], which mainly considers the course of the yaw rate. It is assumed that the course is similar to a sine-wave. Thus the trips are searched for sinusoidal sections of the yaw rate. This is done by searching for local maxima within the absolute signal sequence. By means of the combination of two local maxima with different signs potential lane change manoeuvres are determined. In a subsequent step additional criteria are used to verify the determined lane change manoeuvres.

This approach has been adapted to the specific conditions at the German1-VMC. The thresholds have been adjusted and a further test criterion has been included. The criterion checks the correlation between the course of the lateral acceleration as well as the yaw rate and a sine-wave of the same amplitude and frequency. The main steps of the lane change manoeuvre detection are presented in Figure 9.

**Figure 9. Approach for recognition of lane change manoeuvres**

However a driver dependency is observed for this approach as well.

False detections are observed for manoeuvres which are similar to lane change manoeuvres, such as driving around a traffic island or change onto the opposite lane within a construction site on a motorway. These manoeuvres are usually recognized as lane changes.

In the following the recognition patterns and classification method of incident events are discussed.

**INCIDENT RECOGNITION AND CLASSIFICATION**

Several tested functions are safety related. A major challenge for the evaluation of the functions is the provision of relevant safety impact indicators.
These safety indicators are changes in the number of crashes, fatalities and injuries. But these indicators cannot be directly provided by FOT data, since the expected number of accidents during the FOT is not sufficient to enable statistically valid evaluation. Therefore surrogate measures (e.g. critical TTC, hard braking events) are needed, in order to estimate the changes of the relevant safety indicators. An approach to determine these indicators can be realized by using critical driving situations (incidents). A relation between these incidents and accidents is established by means of an in-depth accident database. Incidents are detected at the German1-VMC by means of a set of indicators composed of time headway, time to collision, relative speed, forward collision warnings, lateral and longitudinal acceleration as well as intervention of the safety systems Anti-lock Braking System (ABS) and Electronic Stability Program (ESP). Moreover the driver intention (derivation from turn indicator, brake pedal usage etc.) is taken into account in order to classify the severity of the incident. Depending on relevant indicator thresholds different levels of incidents can be detected (level 1 to 3):

- An incident level 1 characterizes a driving situation in which the critical threshold of the defined relevant indicator has been reached.
- Level 2 is characterized by an increased accident risk (e.g. loss of control, critical time headway etc.).
- Level 3 is detected in situations with imminent danger of an accident.

Incidents are basically divided into two categories.

1. Incidents due to vehicle dynamics
2. Incidents due to distance behaviour

Incidents due to vehicle dynamics are detected by means of longitudinal and lateral acceleration, yaw rate as well as the state of the ABS and the ESP. The evaluation of the CAN and video data collected within the pilot phase revealed a high number of false detections for the threshold defined based on literature review. For further optimization of the incident recognition test drives with 20 subjects on a pre-defined test track have been conducted and analyzed. Based on these test drives the distribution of relevant indicator thresholds in regular driving situations has been determined for different speed values. The classification of the incident level is partly derived from these test drives. The highest values detected within the test drives have been used as the incident thresholds (level 1 threshold). Figure 10 presents the determined longitudinal acceleration ($a_{long}$) thresholds of the incident levels 1 (low threshold) and 2 (high threshold) for passenger cars and commercial vehicles as a function of the vehicle speed ($v$). For speed values below 50 km/h an incident level 1 (passenger cars) is detected for decelerations higher than 6 m/s². This threshold linearly decreases to a deceleration of 4 m/s² within the speed range from 50 km/h to 150 km/h. For speed values higher than 150 km/h the threshold remains constantly at an acceleration of -4 m/s². This course is the same for passenger cars as well as trucks.

Furthermore several situations were reproduced on a test track and documented by means of video data in order to have a better understanding of the occurrence characteristics of these incident events. Based on this analysis the thresholds for an incident level 2 have been defined. The incident level 2 is detected at higher acceleration values. An incident level 2 for trucks is not speed dependent and is detected as soon as the deceleration value exceeds 7 m/s². An incident level 2 for passenger cars is detected for deceleration values higher than 8 m/s² and is not speed dependent, see Figure 10.

![Figure 10. Thresholds of longitudinal acceleration](image)

**Figure 10. Thresholds of longitudinal acceleration**

The longitudinal acceleration thresholds for passenger cars and trucks are summarized in the following.

**Passenger cars:**
- $a_{long\_low} = -6$ m/s²  \[ < 50 \text{ km/h} \]
- $a_{long\_low} = (-4 \text{ to } -6) \text{ m/s}^2 \times ((v - 50 \text{ km/h}) / 100 \text{ km/h}) + -6 \text{ m/s}^2 \ \ [50 \text{ km/h to 150 km/h}]
- $a_{long\_low} = -4 < 150 \text{ km/h}]
- $a_{long\_high} = -8$ m/s²

**Trucks:**
- $a_{long\_low} = a_{long\_low} \text{ (passenger cars)}$
- $a_{long\_high} = -7$ m/s²

The same approach is applied to determine the thresholds based on the lateral acceleration signal, which is also used to determine incidents. These thresholds are derived from the conducted test drives and applied for detection of incidents level 1 and level 2. The thresholds are defined for passenger cars and trucks as presented in Figure 11.
Figure 11. Thresholds of lateral acceleration

The following incident thresholds for lateral acceleration ($a_{\text{lateral}}$) have been defined.

**Passenger cars:**

- $a_{\text{lateral low}} = (7 - 2.5) \text{m/s}^2 (v < 40 \text{ km/h}) + 2.5 \text{m/s}^2 [ < 40 \text{ km/h}]
- $a_{\text{lateral low}} = 7 \text{m/s}^2 [40 \text{ km/h} to 50 \text{ km/h}]
- $a_{\text{lateral low}} = (4 - 7) \text{m/s}^2 (v < 50 \text{ km/h}) / 50 \text{ km/h} = 7 \text{m/s}^2
- $a_{\text{lateral low}} = 4 \text{m/s}^2 [ > 100 \text{ km/h}]
- $a_{\text{lateral high}} = 9 \text{m/s}^2 [ < 50 \text{ km/h}]
- $a_{\text{lateral high}} = 8 \text{m/s}^2 [ > 50 \text{ km/h}]

**Trucks:**

- $a_{\text{lateral low}} = 2.5 \text{m/s}^2
- $a_{\text{lateral high}} = 4 \text{m/s}^2

Furthermore the yaw rate ($\Psi$) signal is used additionally for detection of incidents. The yaw rate signal is applied only for the detection of level 2 incidents, because these defined yaw rate thresholds imply already a too high rotation rate of the vehicle for the current vehicle speed (e.g. loss of vehicle control). The thresholds for trucks as well as passenger cars are the same and presented in Figure 12. These thresholds are derived from the conducted test drives and only used for detection of incidents level 2.

Figure 12. Thresholds of yaw rate

The thresholds are the same for passenger cars and trucks. The following incident thresholds based on the yaw rate signal have been defined:

- $\Psi_{\text{low}}$ (passenger cars) = $\Psi_{\text{low}}$ (trucks)

- $\Psi_{\text{flow}} = 50 \text{°/s} [ < 40 \text{ km/h}]
- $\Psi_{\text{flow}} = (25 - 50) \text{°/s} * (v < 40 \text{ km/h}) / 10 \text{ km/h} + 50 \text{°/s}
- $\Psi_{\text{flow}} = (15 - 25) \text{°/s} * (v < 50 \text{ km/h}) / 35 \text{ km/h} + 25 \text{°/s}
- $\Psi_{\text{flow}} = 15 \text{°/s} [ > 85 \text{ km/h}]

As an example Figure 13 presents the course of the longitudinal acceleration (m/s²), the turn indicator status and the vehicle speed (km/h) during a test drive for testing the algorithm. During this test drive the algorithm detected an incident level 2 due to the exceedance of the longitudinal acceleration high threshold of -8 m/s² at a vehicle speed of approximately 100 km/h. Furthermore the emergency braking signal (activation of hazard warning light for a short time period) has been activated due to the high acceleration values.

Figure 13. Example of incident detection (level 2) based on exceedance of longitudinal acceleration threshold

These detected incidents have been validated in a further evaluation step by using the corresponding video data.

The second category of incidents is identified by means of the vehicle speed, time-headway (THW), time-to-collision (TTC), relative speed and the state of the brake light. Since the FOT vehicles are equipped with series production sensor systems, only the situation in front of the vehicle can be detected.

For this category a validation by means of the video data from the pilot phase has been conducted as well. The video data has been collected from different vehicle types (trucks, passenger cars) and brands. These pilot vehicles have been driven by different drivers for a period of more than three months. The results revealed a high number of false detections for the first defined thresholds. These thresholds were based on literature review and have been used in other FOTs [7].

As already mentioned most of the previous FOTs used additionally video data to verify the detected situations. Due to the lack of video data at the German-1 VMC the thresholds need to be adapted in
advance (pilot phase) as no further validation is possible for the collected data during the field test. In order to avoid these false detections two different approaches have been used to optimize the detection algorithms.

1. Adaptation of the threshold for incident type due to distance behaviour.
2. Consideration of driver reaction, in order to assess the criticality of the detected incidents.

The approach for assessing the criticality of the incidents is presented in the following.

**Driver reaction**

The idea for considering the driver reaction has been developed after the collected video data of the pilot phase was analyzed in detail. The evaluation of the video data showed that a high number of the detected incidents were not critical, because the driver has been totally aware of the situation. Thus an additional step has become necessary to check whether the detected incident is correct or not by means of the available CAN-information. Various situations during overtaking manoeuvres have been detected as incidents, in which the host vehicle approaches closely to the front vehicle. Within the approaching phase the THW respectively the TTC drops under the incident threshold for a short time period, which is however intended by the driver, in order to perform a quick overtaking manoeuvre. While performing these manoeuvres the driver usually observes also the situation in front of the predecessor, in order to assess whether the predecessor is going to initiate any actions. The probability that the predecessor will perform a hard braking manoeuvre while no vehicle is in front is very low. This information for example is used by the driver to estimate whether a close approaching can be performed for a quick overtaking manoeuvre. Unfortunately this information is not available on the CAN-Bus, because only information on the relevant target (vehicle in front of the host vehicle) is available. Hence the driver is able to consider more information during the driving process. Therefore it is possible that the driver and the algorithms judge a driving situation differently.

In order to reduce this lack of information the driver reaction is additionally considered for the incident recognition. The basic idea of this second step is that the driver intention can be derived by means of the driver reaction. If the situation is in fact critical a driver reaction (e.g. steering or braking manoeuvre) has to be initiated, in order to avoid a collision. If no driver reaction has been detected and no collision occurred, the criticality of these situations is downgraded. In this situation an intention of the driver to perform the manoeuvre (close distance to vehicle in front) and the corresponding driver awareness is assumed.

Before the evaluation of the driver reaction is conducted the criticality of the situation is at first determined by means of the THW and relative speed (Δv) as well as the TTC. Therefore the situation is classified into three different levels. This is the same approach as it is used for the incidents detected by the dynamic behaviour of the vehicle. The thresholds for the three incident levels are shown in Figure 14 as a surface over the host vehicle and front vehicle speed. An incident is always detected, if the distance to the front vehicle drops below the threshold, which is determined based on the host vehicle speed and the speed of the front vehicle.

![Figure 14. Thresholds for an incident level 1 and level 2 recognition based on TTC as well as THW](image)

The thresholds for the detection of level 3 incidents are similar to the level 2 thresholds. The difference between both levels is that a level 2 incident is detected, if the driver is already braking. In contrast a level 3 incident is only detected, if the driver is not braking.

The following thresholds for the different incident levels have been defined for the current version of the incident detection algorithm:

**Level 1:**
- THW < 0.35 s with a slow approach to the front vehicle (10 km/h < Δv < 20 km/h)
- THW < 0.5 s with a fast approach to the front vehicle (Δv > 20 km/h)
- TTC < 1.75 s

**Level 2:**
- TTC < 1 s with braking (brake light switch on)
- THW < 0.35 s with a fast approach to the front vehicle (Δv > 20 km/h)

**Level 3:**
- TTC < 1 s without braking (brake light switch off)

After the incident has been detected and classified to an incident level the analysis of the driver reaction is applied. For this purpose the longitudinal and lateral acceleration as well as the state of the...
turn indicators and the brake light is analyzed for a time period of 5 seconds before and 1 second after the incident has been detected. For each measure different categories have been defined, into which the driver reaction is classified. Based on the different categories the classification of the incident level due to the distance behaviour (TTC, THW and relative speed) is adapted according to the flowchart in Figure 15.

Figure 15. Classification of incident level by means of the driver reaction

After the incident has been detected four validation steps will be applied within the criticality assessment of the detected incident by means of the driver reaction analysis. In the first step the brake light switch will be analysed, in order to check whether the driver performed a deceleration or not. If the brake light switch (indicator for a braking action) has been activated, the longitudinal acceleration is analysed. If the driver has performed a high deceleration the incident level is upgraded by “1” (situation is critical due to reaction of driver). If the longitudinal acceleration was medium, low or the brake light switch off, the lateral acceleration will be checked. In case of high lateral acceleration the incident level is upgraded by “1” (situation is critical due to reaction of driver). For medium and low lateral accelerations the state of the turn indicator is considered in a further validation step. If the turn indicator is not activated and a medium lateral acceleration detected, the incident level will be not changed, because of the driver reaction and especially the fact that the turn indicator has not been used. However, it cannot be clearly identified, whether the driver reaction is intended and a normal driving behaviour or an evasive manoeuvre (not intended).

The incident level will be downgraded by “1” in situations with medium lateral acceleration and activated turn indicator as well as situations with low lateral accelerations and activated turn indicator. An incident level is downgraded directly to zero in situations with low lateral acceleration and not activated turn indicator. In these situations the driver did not react at all and no collision is detected afterwards. Thus it will be classified as non-critical.

Figure 16 presents the course of vehicle speed, longitudinal acceleration and time headway during a trip collected within the pilot phase, in which an incident is detected. The incident occurs at a relative speed of 30 km/h (fast approaching to leading vehicle). In the beginning the incident severity is classified as level 1, because of the relative speed and critical time headway less than 0.4 s. Afterwards the driver initiates a hard deceleration of a maximum value of 6.9 m/s². In combination with a hard deceleration the incident level has been upgraded to level 2, because a strong driver reaction is necessary to resolve the situation.

Figure 16. Recognition of an incident by means of THW and longitudinal acceleration

The second objective of considering the driver reaction is to avoid false incident detections due to incorrect sensor information (e.g. “phantom” object detection). In case of a false object detection the driver will not react to the detected “phantom” object, because the driver is obviously not aware of this object. If the driver does not react to the situation (no braking, steering action etc.), the incident level is downgraded to zero, which means that the situation is classified as non-critical as presented in Figure 15.

By means of considering the driver reaction as well as the adjustment of the thresholds for the incident detection the number of detected incidents as well as the number of false detections within the pilot phase has been significantly reduced from 75% to 3%. The results of the comparison between the first version of the algorithm and the current version (adapted version) are presented in the following table.

By means of this second step a significant higher reliability rate for incident detection at the German1-VMC has been achieved.

Benmimoun 10
Table 1.
Number of incident detections during pilot phase

<table>
<thead>
<tr>
<th>Number of incidents</th>
<th>Current version</th>
<th>First version</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total detections</td>
<td>31</td>
<td>145</td>
</tr>
<tr>
<td>False detections</td>
<td>1</td>
<td>109</td>
</tr>
</tbody>
</table>

By means of the criticality assessment a significant higher reliability rate for incident detection at the German1-VMC has been achieved.

SUMMARY & CONCLUSIONS

In this paper the approach for incident detection at the German1-VMC within the field operational test euroFOT project has been presented. Especially the methodology as well as the developed data management processes for data upload, processing and storage have been introduced. Furthermore the challenges faced during the implementation phase for data processing (e.g. event recognition, harmonization of different signal outputs etc.) are exemplified. The approach and the particular conditions at the German1-VMC for detection of incidents are presented in detail.

The detection of incidents has been revised after the evaluation of video data from the pilot phase. This data revealed a high number of false detections. The current version of the incident detection divides the incidents into two categories (incidents due to vehicle dynamics and distance behaviour). Moreover the driver reaction has been integrated as an additional step for verification purposes. By means of the driver reaction the level of detected incidents due to distance behaviour (THW, TTC and relative speed) are verified. By means of video data modifications of the incident detection algorithm have been made (including verification by means of the driver reaction step and adjustment of thresholds), which result in a significant reduction of the number of false detections from 75% to 3%. The evaluation of the current version showed a reliable detection for different conditions, vehicle types and drivers within the pilot phase.

However, the collected video data within the pilot phase might not be sufficient to validate the detection effectiveness of the developed incident algorithm in all driving conditions. Thus a validation by means of video data is preferable, which is collected for a longer time period.

Moreover it has to be taken into account that the defined thresholds are very “conservative”, in order to ensure a reliable recognition by means of the available CAN-data. But they might lead to non-detections of actual incidents (e.g. distracted driver, driving under influence of alcohol, drowsiness etc.). Further video analysis of these specific events can be used to optimize the algorithm by considering the characteristic of these events. For this a high number of the described events need to be collected and analysed. This requires a data collection phase of video as well as CAN-data for a time period of several months (e.g. one year).

REFERENCES


