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REVIEW OF EVALUATION PROCEDURES RELATED TO SAFETY SYSTEMS

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Abstract

During the past decade several eSafety systems were developed for vehicles and promising future improvements of road safety are expected to rely on such safety functions. Especially for active safety systems attempting to avoid accidents through active support to the driver, which are currently under rapid development, no generally accepted assessment program is in place, thus there is a need for standardised testing and assessment methods.

The objective of this research is the examination of existing test procedures used for the evaluation of various technological systems related to vehicle safety. For that reason a thorough literature review was carried out in to identify the most appropriate procedures that are currently used or are under development to test the various technological systems and examine if these procedures are relevant to road accident problems. The difference between active and passive safety is explained and the intelligent transport systems are categorised in two different ways. The different organizations and bodies involved to the development of the test procedures are described, as well as methodologies for testing and evaluation of preventive safety functions that have been addressed in several research projects in Europe and US during the last years are presented. Moreover, several test procedures concerning active safety are described in a standardised way, and some detailed information regarding ISO and SAE standards is provided.

The results of the research revealed that while test methods for validation of ICT-based safety systems with drivers in the loop are not widely applied, there are certain methods for testing specific systems, mainly given by means of standards. The measured data recorded through testing procedures can be used to calculate safety performance indicators describing the performance of the safety function and the evaluation of a safety system for regulatory consideration requires full attention and further concrete steps that could involve educating consumers on the merits of a safety system, incentivizing automobile manufacturers to make the system readily available or further analyzing the system.

This work has been undertaken in the EC funded DaCoTA project

Key-words
Active safety systems, test procedures, system evaluation

1. INTRODUCTION

Modern society strongly depends on mobility and the need for transport of both people and goods is expected to grow further in the future. Consequently, cleaner, safer and more efficient transport systems are needed. Mobility and especially road transport, cause major societal problems, namely accidents, pollution, congestions etc. More than 34.000 people were killed in 2009 in road accidents in the European Union only, and the related costs are estimated to about 2% of its GDP (DaCoTA, 2012).

Road safety has been increasing in motorized countries showing that political willingness and efficient countermeasures can actually produce positive results. The last couple of decades have seen especially a promising increase in eSafety systems directly linked to technological progress. These systems are complementary to traditional safety countermeasures (regulation, education, enforcement, advertising and information campaign, car crashworthiness, infrastructure improvements, etc.). eSafety systems address accident prevention (preventive safety), accident avoidance (active safety), injury mitigation (passive safety) and rescue and health care improvement. eSafety does not only concern stand-alone car technologies, but embraces also road infrastructure safety, traffic also car-to-car or user-to-user communication or any kind of countermeasures linked with the availability of new technology, contributing to accident and injury prevention.

The main factors related to road accidents can be grouped in three broad categories: Road users, road infrastructure and vehicles. Regarding the vehicles, during the past decade several eSafety systems were developed, intended to assist, inform or alert the driver by addressing one or several driving tasks, by amplifying driver actions, by correcting a problem, by preparing and providing car occupant or external user protection in the case of an accident, or even by relieving the driver of certain tasks. Certainly, some other systems are protecting the car occupants in combination with a stiffer and enhanced car structure. Initially, mainly passive safety systems were introduced, i.e. systems of airbags, seat belts and protective structures that increased safety for the drivers, passengers and more recently, pedestrians. Furthermore, relevant testing programs for assessment of these passive safety measures have been established.

Active safety functions such as Electronic Stability Control (ESC) and Lane Departure Warning (LDW) are under rapid development and have also been introduced, attempting to avoid accidents through active support to the driver. Promising future improvements of road safety are expected to rely on such safety functions with the aim to prevent accidents from happening and for these functions, in contrast to passive safety, no generally accepted assessment program in place (E-value, 2008).

Several initiatives have identified the need for standardised testing and assessment methods over the past years. While some of them are on-going and similar, different methods have been presented recently and are discussed within this research. Evaluation of the functional performance of a preventive safety system considers the technical performance of the function as well as the overall safety effects (i.e. evaluation that the function does what it was designed for). Technical performance testing aims at investigating whether a safety function meets technical requirements and specifications on what the function shall do.

The objective of this research is the examination of existing test procedures for various technological systems for vehicle safety. For that reason a literature review was carried out to identify the most appropriate procedures that are used to test the various technological systems and examine if the currently used test procedures are relevant to road accident problems.

In order to achieve the objective, initially, the general terms are defined, as well the difference between active and passive safety is explained and the intelligent transport systems are categorised in two different ways. The different actors involved to the "test procedure" are described and methodologies for test and evaluation of preventive safety functions that have been developed in several research projects in Europe and US during the last years are presented. Moreover, several test procedures for active safety are described and some more detailed information regarding ISO and SAE standards is provided.

This research is based on work carried out within the DaCoTA (Data Collection Transfer and Analysis) research project, co-funded by the European Commission within the 7th Framework Programs for Research, Technological Development and Demonstration.

2. CATEGORISATION OF SAFETY SYSTEMS

Intelligent Transport Systems is an umbrella term for a number of electronic, information processing, communication, and control technologies that may be combined and applied to the transport domain. ITS may refer to a single technology, an integrated system, or a network of systems and may be categorized in several ways, referring either to the physical location of the system, the timing of the effects of the system, the means by which the system enhances safety, or the transport domain to which they are applied.

One of the broadest and most common classifications regards the positioning of the system – i.e., whether system is in-vehicle, infrastructure-based or cooperative:
In-vehicle systems refer to technologies based within the vehicle. These typically involve sensors, information processors and on-board units or displays that provide additional information to the user, automate or intervene with some part of the driving task, or provide warnings to the user about potential hazards. Infrastructure-based systems may serve one of two general functions: to provide drivers with additional information via roadside messages, or to better manage and control traffic flow. In both instances, various types of sensors are used to gather information from the road environment and road side signs or signals are used to influence traffic behaviour. Finally, cooperative systems involve communication between vehicles and the infrastructure or between vehicles. This communication may be one way, i.e. where the vehicle receives information from the infrastructure but does not transmit information in return, or two-way where the vehicle both sends and receives information to another vehicle or infrastructure-based system (DACOTA, 2012)

Another classification mean of ITS, is to differentiate when the system takes effect (passive – active). Since the systems are fundamentally different in nature, it is helpful to trace the development of each system separately.

Passive safety systems are automobile safety systems that are only deployed or effective in response to an automobile accident. These systems protect drivers and passengers from injury once a collision occurs. Passive systems include seatbelts, head restraints, front driver and passenger airbags, side impact bars, head protecting side airbags and fuel pump shut-off devices (NHTSA, 2007).

Active safety systems help drivers avoid accidents. These systems function behind the scenes, monitoring the driving conditions and actively adjusting the driving dynamics of the vehicle to minimize the risk of an accident. Active systems provide a degree of protection for occupants unavailable in passive systems and they reduce the likelihood of a situation that would require the use of Passive systems. Active systems include anti-lock brake systems, Adaptive Cruise Control, Forward Collision Warning and Avoidance, Lane Keeping Assistance etc. (TRACE, 2007)

The development of road vehicles during the past decade has led to vehicles with improved passive safety. Systems of airbags, seat belts and protective structures have increased safety for the drivers, passengers and lately also pedestrians. Testing programs for assessment of these passive safety measures have been established worldwide but the same does not also apply to active safety systems for which a need for a harmonised and compatible test programs is identified in scientific community.

3. ORGANISATIONS AND BODIES DEVELOPING TEST PROCEDURES

Different organizations and bodies are involved to the development of safety systems' test procedures and several methodologies for testing and evaluation of preventive safety functions have been addressed in research projects in Europe and US during the last years.

The ISO (International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees; each member body interested in a specific topic for which a technical committee is established, has the right to be part of that committee. International organizations, governmental and non-governmental departments in liaison with ISO also take part in the work and ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

For the purposes of this research, several ISO standards for test procedures were examined covering different safety systems, as briefly described below:
ISO 15622:2002 classifies ACC systems into four different types and four different performance classes with respect to curve radius capability and contains seven parts: scope, normative references, symbols, classification, requirements, and performance evaluation test methods, while ISO 17362:2007 classifies Lane Departure Warning Systems (LDWS) into two types with respect to vehicle speed and curve radius capabilities and contains five parts: scope, normative references, terms and definitions, specifications and requirements, and test method. The standard also contains one annex on national road markings. Regarding Lane Change Decision Aid System (LCDAS), ISO/DIS 17387 specifies system requirements and test methods for the which is intended to warn the driver of the subject vehicle against a potential

collision with target vehicles moving in the same direction during a lane change manoeuvre.

ISO 17386:2010 addresses light-duty vehicles, e.g. passenger cars, pick-up trucks, light vans and sport utility vehicles (motorcycles excluded) equipped with MALSO (Manoeuvring Aids for Low Speed Operation) systems. It specifies minimum functionality requirements which the driver can generally expect of the device, i.e., detection of and information on the presence of relevant obstacles within a defined (short) detection range and ISO 22178:2009 contains the basic control strategy, minimum functionality requirements, basic driver-interface elements, minimum requirements for diagnostics and reaction to failure, and performance test procedures for Low Speed Following (LSF) systems.

ISO 15623:2002 specifies performance requirements and test procedures for systems capable of warning the driver of short inter-vehicle distance and closing speed which may cause a rear-end collision with other vehicles, including motor cycles, ahead of the subject vehicle while it is operating at ordinary speed. ISO 22840:2010 for Extended-Range Backing Aids (ERBA) addresses light-duty vehicles e.g. passenger cars, pick-up trucks, light vans and sport utility vehicles (motorcycles excluded), equipped with such ERBA systems. ISO 22840:2010 establishes minimum functionality requirements that the driver can expect of the system, such as the detection of and information on the presence of relevant obstacles within a defined detection range. Moreover, it sets minimum requirements for failure indication as well as performance test procedures.

The SAE International (Society of Automotive Engineers) also has committees developing standards related to active safety systems. The most relevant committee is the Safety and Human Factors steering committee within the Vehicle Safety Systems group. Other relevant SAE groups and committees are: Safety Systems Component Advisory group, Truck and Bus Brake Systems committee and Highway Time Forum Steering committee.

J2400_200308 describes elements for a Forward Collision Warning operator interface, as well as requirements and test methods for systems capable of warning drivers of rear-end collisions. This Information Report applies to original equipment and aftermarket FCW systems for passenger vehicles including cars, light trucks, and vans. Furthermore, J2802_201001 specifies the minimum recommendations for Blind Spot Monitoring System (BSMS) operational characteristics and elements of the user interface and regarding Light Vehicle Dry Stopping Distance J2909_201005 establishes best practices to measure vehicle stopping distance on dry asphalt in a straight path of travel intended for the purpose of publishing stopping distance by manufacturers and media organizations

The following Table summarizes which standards are used for the evaluation of the most widely used safety systems.

Table 2: Connection between different standards and systems

Standard/Report	ACC	FCW	BSD	LKA	LDW	ABS	ESC
ISO 3888-1:1999							•
ISO 3888-2:2002							•
ISO 6597:2005						•	
ISO 7401:2003							•
ISO 7975:2006						•	
ISO 15622:2002	•						
ISO 15623:2002		•					
ISO 17361:2007					•		
ISO/DIS 17387			•	•			
ISO 21994:2007						•	
ISO/DIS 22178	•						
ISO/DIS 22179	•						
SAE J2399	•						
SAE J2400		•					
SAE J2478				•			
SAE J2536						•	
FMCSA-MCRR-05-005					•		
FMCSA-MCRR-05-007	•	•					
FMVSS 126							•
GRRF-63-26							•

The National Highway Traffic Safety Administration (NHTSA) in the US has proposed three test procedures for FCW, LDW and ESC systems which are related to US NCAP (New Car Assessment Programme) assessments. EuroNCAP has a specific test protocol for ESC systems and other active safety systems can be rewarded (Euro NCAP Advanced) by using the Beyond Euro NCAP Assessment Protocol. ESC systems are rewarded if fitted in the assessed vehicle in the Australasian NCAP (ANCAP). Other NCAP organizations are: Japan NCAP (JNCAP), China NCAP (C-NCAP) and Korea NCAP (KNCAP).

4. INDIVIDUAL TEST PROCEDURES

Apart from the standard test procedures that are developed by the various organisations and bodies worldwide, there are also individual test procedures that were examined. The most commonly used individual test procedures are briefly described below:

The obstacle avoidance test, known as moose or elk test, had been introduced in order to demonstrate the tipping stability of vehicles. However, the test conditions allowed the driver many degrees of freedom during the performance of the tests meaning that due to the driver's influence the test did not produce any objective and reproducible results. The VDA revised and re-defined several parameters such as the obstacle avoidance test, the course (measuring a total length of 61m), the time measurement and the accelerator pedal release corresponding to the typical driver behaviour. Eight metrics are specified for this procedure but it can still only produce limited conclusions about the tipping stability of vehicles (DTA, VDA Lane Change, 2009).

The steady-state circular test is an open-loop test, driven according to the methods of constant radius, constant steering wheel turning angle or constant speed. The tests are performed with constant transverse accelerations in standardized steps all the way up to the driving dynamics limits. The course of the steering wheel turning angle over the increasing transversal acceleration is an important evaluation criterion for the self-steering behaviour of the vehicle. Its increase is an indication of under-steer and developers normally strive to achieve an under-steering to neutral self-steering behaviour. However, it is certainly a question of vehicle set-up philosophy to what extent the gradient of yaw speed and steering angle approaches the critical speed, and the vehicle responds most sensitively to steering inputs in the process (DTA, Steady-State Circular Test, 2009).

Braking from Steady-State Circular Motion serves the main objective of determining the effect of braking on the directional behaviour of a vehicle whose steady-state circular motion is only interfered with by the response of the brake. Similar to the situation that occurs during load alteration, the vehicle tends to turn toward the inside of the corner, which forces the driver to perform quick steering corrections. The related test is carried out under specific circumstances and twelve measurands are specified. The test revealed that in braking events up to mean decelerations, a maximum yaw moment occurs when the longitudinal forces in the tire contact patch change due to shifting wheel loads. The higher wheel loads lead to a reduced slip angle at the front axle and an increased slip angle at the rear axle. This causes the instantaneous center of rotation vis-à-vis the position in the un-braked state to significantly shift forward and closer to the vehicle, thus resulting in a smaller cornering radius. At maximum deceleration, the effect is determined by the locking sequence of the wheels and thus by brake force distribution. However, when ABS is used this differentiation is no longer relevant (DTA, Braking from Steady-State Circular Motion, 2009)

The Lane Change test procedure in which 12 measurands are specified, is suitable for demonstrating how precisely, fast and spontaneously the vehicle responds to the driver's steering angle inputs. The highest possible entry speed was measured at just under 70 km/h for the measurement vehicle. However, the lane change test allows only limited statements to be made about the vehicle's tilt stability (DTA, Straight line Braking, 2009)

Finally, during Step Steering Input the vehicle's response to sudden step steering input enables statements to be made about the speed of response, vehicle stability under the existing conditions as well as for the precision of the steering system. In case of a major phase delay between steering wheel input and yaw speed the vehicle can be perceived as inert and possessing poor cornering ability. If during the change from the unsteady to the steady-state phase of the step steering input, yaw speed and lateral acceleration exhibit large amplitudes and long transient periods, then vehicle stability may be jeopardized. The gain factor, the quotient of yaw speed and the steering wheel angle, is a measure of how much steering angle the driver needs in order to generate a certain yaw response. A precise steering system is characterized by a large gain factor (DTA, Step Steering Input, 2009)

5. RELEVANT RESEARCH PROJECTS

Strategies and methodologies for testing and evaluation of preventive safety functions have also been addressed in several research projects in Europe and US during the last years. While the PReVENT project addressed how to evaluate different systems (PReVENT, 2008), the focus of the AIDE project was on methods for evaluating IVIS, but these methods could also be used in evaluation of preventive safety functions (acceptance, workload and usability) (AIDE, 2008).

The ASTE study investigated the feasibility of setting up an objective test program for intelligent vehicle safety systems. The aim of the work was to assess the feasibility of setting up an independent performance and conformance testing programme for Intelligent Vehicle Safety Systems, to define required methods and principles for verification and validation of Intelligent Vehicle Safety Systems and to evaluate if a consensus of the proposed principle can be achieved with different stakeholders (ASTE, 2007).

In Aprosys, in order to achieve the next significant step in traffic safety, two novel technologies have been applied for the first time in an automotive application. A side-impact detection system using stereo video and radar sensors and a Shape-Memory-Alloy based structural actuator. As a technological showcase, these technologies have been combined in an integrated side-impact protection system. The system was derived from accident statistics, as was the test programme. The latter has proved finally the effectiveness of the two technologies (APROSYS, 2011).

E-Value addressed the real function of ICT-based safety systems and their capability to perform the function through two courses of action: defining and quantifying the function output to be achieved by the safety system and developing the testing and evaluation methods for the ICT-based safety systems. The safety systems within the eVALUE scope are classified into four clusters: longitudinal, lateral and yaw/stability. The fourth cluster remained open for upcoming systems. (E-value, 2008).

Moreover, the overall purpose of the ASSESS project was to develop a relevant and standardised set of test and assessment methods and associated tools for integrated vehicle safety systems with the focus on currently “on the market” pre-crash sensing systems. The information and methodology developed in this project can then be used for a wider range of integrated vehicle safety systems, encompassing assessment of driver behaviour, pre-crash performance and crash performance. (ASSESS, 2010).

In addition, the purpose of the CIB project is to develop and validate performance requirements and objective test procedures for CIB systems and to assess the harm reduction potential of various system configurations with differing performance capabilities. CIB systems with adjustable characteristics will be integrated into test vehicles in order to develop minimum performance requirements and further characterize the vehicle system performance sensitivity to the pre-crash sensor specifications. These results will be augmented with the final tests exercised on a limited number of system configurations. Data obtained during testing will be used to develop preliminary estimates of potential benefits of these prototype systems. (CIB, 2010).

6. CONCLUSIONS

The objective of this research is the examination of existing test procedures for various technological in-vehicle safety systems. As a baseline, the technologies and components currently used in ICT based safety systems as well as existing testing and evaluation methods have been collected and analysed and an overview of the different systems that are currently available or under development, with aim to increase vehicle safety has been given.

While test methods for validation of ICT-based safety systems with drivers in the loop are not widely applied, there are certain methods for testing specific systems, mainly given by means of standards. Additionally, some research projects have already been carried out in the field of eSafety systems testing and evaluation. Their focus was mainly on strategies and methodologies for testing active safety systems.

Through testing procedures, a significant amount of data is recorded. These data have to be processed and interpreted in an efficient way. The measured data can then be used to calculate safety performance indicators describing the performance of the safety function. Post-processing of measured data should be automatable and representative in a clear format and results should be understandable by different recipients. While experts are able to interpret precise measurements, end customers should be provided with abstracted values, e.g. by means of a rating.

The evaluation of a safety system for regulatory consideration is not completed after a value is determined and a decision is made whether to presently consider the system or to defer its consideration indefinitely. An evaluation that indicates present consideration requires full attention and further concrete steps. Such steps could involve educating consumers on the merits of a safety system, incentivizing automobile manufacturers to make the system readily available or further analyzing the system.

As a future step the recommendation for new test procedures can be attempted, when necessary, enabling specific technological systems to approach as much as possible the real conditions and cover a wider part of the "real world" road safety problems.

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