DEVELOPMENT OF A GENERIC ASSESSMENT METHODOLOGY FOR ADVANCED SAFETY SYSTEMS

Mike McCarthy
TRL Limited (on behalf of the APROSYS 1.3 consortium)
United Kingdom
Paper Number 09-0286

ABSTRACT

Advanced safety systems which use pre-crash sensing information from the environment and/or the vehicle occupants have an "active response" which improve primary or secondary safety. Many systems are in development which use pre-crash sensing information as a decision input and it is widely predicted that the implementation of such safety systems, together with appropriate actuators and control algorithms, offer significant safety potential.

Existing test methods evaluate the crash performance of a vehicle, but are unsuitable for the assessment of advanced safety systems because additional evaluations of the sensing performance and the effect of autonomous actions on the driver response are required. To meet this need, work package 1.3 of the European Advanced Protection Systems (APROSYS) project developed a generic methodology which was intended to define guidelines for development of a specific test programme. This paper presents the final generic methodology for advanced safety systems and details a 'test case' carried out to demonstrate the application of the methodology.

INTRODUCTION

The European 6th Framework Programme Integrated Project (IP) on Advanced Protection Systems (APROSYS) was focused on developments in the field of vehicle safety. Within work package 1.3 (WP 1.3) "Advanced safety functions", the objective was to develop an evaluation method for the assessment of advanced safety systems that employ pre-crash information from environmental sensor systems. As defined in APROSYS deliverable D1.3.1 [1], these systems were considered to be *primary or secondary safety systems that adapt to different scenarios to reduce accident severity and/or injury risk.* These systems use sensed occupant data and/or pre-crash information obtained from environmental sensors and vehicle data.

This definition covers a broad range of advanced systems, ranging from occupant classification systems for intelligent airbag and restraint deployment, to pre-crash braking or other collision mitigation and avoidance systems.

The methodology developed was intended to be generic in terms of the systems to which it could be applied and also in terms of the application of the assessment. For example, the methodology could be used by OEMs in development, regulators as the basis for type approval compliance, or consumer information organisations to provide information on advanced system performance.

Current Regulatory Compliance

For a vehicle to gain type approval, it must satisfy the requirements of EC Directive 92/53/EEC. Article 8(2) of Directive 92/53/EEC (amending Directive 70/156/EEC), prescribes that if the vehicle is equipped with technologies or concepts incompatible with current directives, the Member State should provide a report containing:

- The reason why the technologies prevent the vehicle or component from complying with the requirements of the relevant(s) Directive(s);
- A description of the areas of safety and environmental protection concerned and the measures taken;
- A description of the tests and their results that demonstrate at least an equivalent level of safety and environmental protection as is provided by the requirements of one or more of the relevant separate Directives;
- Proposals for amendments to the relevant separate Directives or new separate Directive(s) as applicable.

In the case of systems involving pre-crash sensing, a modification of the vehicle behaviour or safety system to improve the level of protection offered is made. Thus, in order to gain regulatory compliance, proof that the sensor and actuator system function as intended is necessary. Tests of the sensor, actuator, and the effect on safety of false triggering are required for most systems employing pre-crash sensing. For example, this is true for pre-crash pedestrian systems. However, in the case of some advanced safety systems, for example reversible occupant systems, it is considered that these could

function in existing regulatory and consumer crash tests.

For autonomous pre-crash braking there is a compliance issue with all current legislative and consumer crash tests because such a system would reduce the impact speed prescribed by regulatory tests. In this case, the pre-crash braking should be deactivated for the regulatory test and further tests to demonstrate the system function and safety carried out to prove that the sensing and activation of the system is appropriate and that the activation of the system only occurs in the unavoidable accident phase.

Systems which take control of the car away from the driver are also in conflict with at least some interpretations of the wording of the 1968 Vienna Convention, which states that the driver must be in control of the vehicle at all times. The content of the relevant sections of this convention may require amendment to reflect the significant technical developments in advanced safety systems, which take control away from the driver, providing that the safety implications of this action can be scientifically justified and assessed using an agreed methodology.

GENERIC ASSESSMENT METHODOLOGY FOR ADVANCED SAFETY SYSTEMS

The generic evaluation methodology developed by APROSYS *is suitable for use by a wide variety of stakeholders, for example, consumer organisations, legal authorities and industry*, all of whom have a need to verify or evaluate the technical performance of pre-crash safety systems.

In case of regulatory approval, the route for advanced safety systems is currently defined by Article 8(2) of EC Directive 92/53/EEC. Advanced safety systems which are incompatible with existing Directives require additional testing, but the evaluation methodology is not defined. *In the future, this generic methodology could be used as a basis for these tests to assure a minimum performance requirement for advanced safety systems.*

Description of the Generic Methodology

The generic evaluation methodology is shown in Figure 1. In the following sections, each the stage of the flowchart is described in greater detail. The following sections should therefore be read and interpreted with reference to Figure 1.

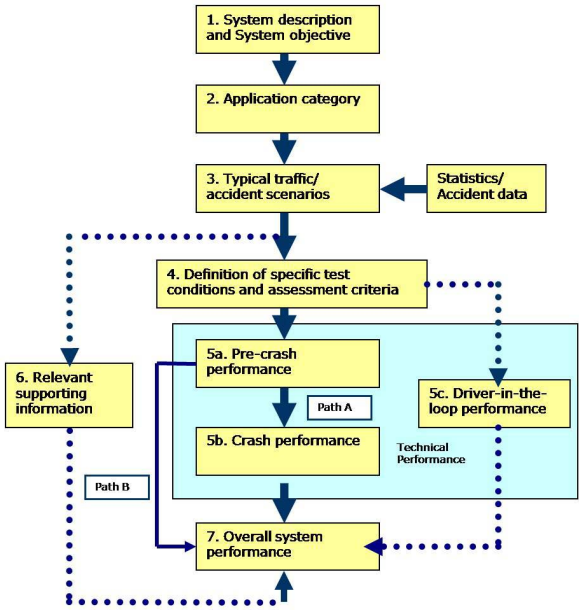


Figure 1. Flow chart for the generic assessment methodology for advanced safety systems.

<u>System Description and System Objective</u> - The system description is a brief description of the product or function to be evaluated. The following key characteristics of the system should be addressed:

- The application name and type;
- The major technologies and application under assessment (especially relevant for integrated systems);
- The functionality or service offered by the system;
- Any technical system limitations in terms of the conditions under which the technology is not designed to function effectively (e.g. in darkness or above/below certain speed thresholds).

The evaluation process should *always be performed for the complete system which offers the stated function.* For example, if sensing systems provide information to multiple systems, the information from the sensing system should be assessed separately for each function.

The objective of the system *will provide the key indicators to determine the parameters which must be assessed in the evaluation of the system*. Therefore, it is necessary to specify the manner in which the system is expected to reduce the injury risk. The description should also include limitations relating to the intended system objective. Further to any technical limitations, the limitations on performance should be noted. For example, the performance of an

emergency braking system would be reduced by a low friction road surface, despite the fact that the sensing system functions appropriately.

Application Category - In the application category, information should be provided regarding *the road-user groups and accident types in which protection is offered*. The categories of road users protected by the safety system are recommended as follows:

- car occupants
- truck and bus occupants
- non-motorised vulnerable road users
- motorcyclists

The broad categories of accident types for which the safety system is considered relevant are listed below. Note that this is not necessarily the direction in which the sensor information is focussed:

- frontal impact
- lateral impact
- rear-end impact
- rollover

In addition, the vehicle category to which the safety system is implemented should be identified and this, along with the application category, used as input for box 3 where the relevant accident types are identified.

Typical Traffic / Accident Scenarios - In box 3, *a set of generic scenarios should be defined based on accident data or real world situations*. These should include relevant accident scenarios and, depending on the type of system and actuator, relevant traffic scenarios that may include situations with a high accident risk, near miss scenarios, and other critical situations.

The definition of relevant scenarios is a critical step in defining appropriate test conditions because these must be representative of the most important situations in the real world for which the system is expected to provide a benefit. Thus, it is recommended that the scenario selection process consider the following general steps:

- Identify an accident data source that is applicable in scope and level of detail which is representative of the region for which the assessment is being made;
- Identify accidents which occurred in general conditions where the system should be functional (i.e. design limitations of the system are excluded);
- Identify accidents involving the user group for which the system is designed to offer a benefit;
- Assess frequency of fatal and/or seriously injured casualties by accident parameters, including, but not limited to: road type, impact speed, impact angle, impact object, road conditions.

In addition, accident and injury causation should be examined. Although this information may not be necessary to define the test scenarios, it is important for estimating the injury benefit of the advanced safety system. It is recommended that the relevant scenarios are identified based on the accident types resulting in the greatest frequency of fatalities, since this criteria is more directly comparable among European countries than other severity levels or national cost benefit values.

Definition of Specific Test Conditions and Assessment Criteria - In the box "definition of specific test conditions and assessment criteria", *the test conditions and the assessment criteria should be defined for the pre-crash tests, crash tests and driver in the loop tests*. In addition to test conditions developed from accident data, test conditions may be developed which are not derived directly from box 3, e.g. to assess environmental conditions that are expected to be more complex for the sensor system and which are not recorded in existing accident data. Details regarding the test conditions should be defined, including possible new test devices which might be necessary, for example new test environments, new barriers for the sensor tests, or new types of impactors or dummies for crash tests.

The assessment criteria used to evaluate the benefit of the advanced safety system should be defined. Standard legislation or consumer crash test criteria could be used for this purpose. However, other criteria may be used to assess the system. Note that the definition of the test conditions and criteria were outside the scope of this work, since this is application and system specific. Therefore, this should be addressed by the party applying the generic methodology. Within WP 1.3, this process was performed for a pedestrian pre-crash system to evaluate the applicability of this methodology.

Technical Performance - The assessment of the technical performance of the safety system is achieved by *the assessment of the pre-crash performance, the crash performance, and the driver in the loop performance*. Within the methodology presented here, evaluation of the driver-in-the-loop

performance was considered a compulsory component if the driver behaviour could influence the performance of the system. In the case that this methodology is being used to obtain compliance with existing or future regulation, "driver in the loop" tests should be performed to ensure that the pre-crash system does not have a negative influence on the driver during trigger events, and that the level of safety is not less than that without the system fitted.

Assessment of Pre-crash Performance - For pre-crash performance, *test scenarios and criteria defined in box 4 will be used in non-destructive tests to assess the pre-crash performance of the system*. A range of scenarios should be assessed ranging from very relevant (but simple) to less relevant (but more complex). The number of test scenarios passed by the system may be used to rate the pre-crash performance. In this way it can be shown that the system works as intended in a defined proportion of real world accident cases, since the test scenarios can be defined as covering a percentage of the real world accident data cases.

For each individual advanced safety system, specific criteria are required to evaluate the pre-crash performance in the defined accident scenarios. One possible convenient assessment criterion which could be applicable for some safety systems is the trigger time. If this time is not available, the 'system-in-function time' might also be used as an assessment criterion. The 'system-in-function time' is defined as the time at which the system offers the designed level of protection. In some cases it may be problematical to obtain this measure, especially as it might be impossible to gain direct access to the system on a signal level. For the Pedestrian GTR (Global Technical Regulation) it was proposed that the manufacturer provides both the head impact time and the sensor time. Based on this information it is decided if the head-to-bonnet impact tests can be performed with the bonnet in its deployed state [2].

For some systems, a minimum system-in-function time might not be an appropriate criterion, because an exact timing of the complete activation of the system could be necessary for optimal system performance. For example, for some type of pedestrian protection airbag systems, the airbag timing is critical to the level of safety offered. Thus for these systems, not only a minimum system-in-function-time, but also a time window of activation must be determined. An appropriate method must be developed for each specific safety system under assessment.

After the pre-crash performance has been assessed, two different paths can be followed to complete the system evaluation:

- Path A should be followed in case the actuator is expected to have an influence on the crash performance, or if the crash performance is not available;
- Path B should be followed in case the actuator will not influence the crash performance and the crash performance without the system is already available, for example a driver warning system.
- For both paths, if the system effectiveness could be influenced by the driver response, then driver in the loop tests should form part of the system evaluation.

Assessment of Crash Performance - If path A is followed, the crash performance must be assessed using the measured pre-crash performance. Using existing test procedures from regulations or consumer tests as a basis, the actuator system will be triggered (by the sensing system or synthetically) according to the results of the pre-crash performance tests. During the test, measurements will be made according to the standard procedures (if they are available) and the results will be compared and rated using the standard crash test as a reference.

For some new safety systems, the existing procedures from regulations or customer tests might not be appropriate to measure the crash performance. For example in some cases the dummy kinematics could be significantly different to those of a real occupant or the dummy injury criteria might not be sensitive enough to accurately represent any injury benefit. In such a case, other additional methods might be considered. This could include using new testing devices as well as numerical simulation (e.g. human body models) to evaluate the benefit of the system.

Assessment of Driver-in-the-Loop Performance - In the driver in the loop tests, the scenarios and criteria defined in box 4 will be used to investigate if and how the system activation influences the safety of the occupants. The influence could be negative (e.g. in terms of distraction in case of a false alarm) or neutral. In addition, driver-in-the-loop tests are important to evaluate the driver reaction, or to generate missing input for scenarios. Driving simulators or subject trials are tools which could be used to evaluate the driver-in-the loop performance.

Relevant Supporting Information - This box provides the manufacturer of the system the opportunity to provide additional larger scale or longer term information to the evaluation. Studies may be retrospective (using accident data) or realistic estimations based upon field studies or numerical simulations. Examples include:

- driving tests with professional drivers;
- field operational trials
- large scale driving simulator tests;
- accident data collection to monitor real world effectiveness

This generic methodology is focussed the assessment of technical performance. However, information supplied by the OEM or tier one suppliers regarding the longer term effects, and the "on the road" system effectiveness are an important part of the assessment of pre-crash systems. This information may be supplied from manufacturer testing carried out in the development phase. Furthermore, it is recommended that for any future regulation, and for systems gaining approval under the current Article 8 (2) route, this information should be mandatory. This evidence will demonstrate the safety of the system in a much greater range of road situations than can be assessed in specific evaluation tests. Future regulation may wish to explicitly specify the requirements for these tests.

Overall System Performance - At the system performance stage, the quality of the overall system must be evaluated. Therefore, *the driver-in-the-loop performance, the pre-crash performance and the crash performance will be combined to calculate an overall system performance.* The procedure to determine the overall system performance has yet to be developed since it is dependent on the specific application of the generic methodology. The procedure to assess the overall system performance, including the performance limits, may be different depending on the application of the assessment. The focus in regulatory testing is to guarantee a minimum performance requirement which systems must fulfil to be admitted to the market, whereas the intention of consumer information schemes are to differentiate between the performance of products available on the market.

A casualty benefit estimate could be made by considering the size of the target population; the number of fatal, serious and slight casualties which the system might influence. The results of the testing phases could then be used to estimate the effectiveness of the system in influencing the target population. This would lead to an estimate of the casualty reduction estimate of the system based upon the actual system performance as measured by the test developed using the generic methodology.

APPLICATION OF THE GENERIC METHODOLOGY TO A SPECIFIC SYSTEM

The generic methodology was evaluated by applying it to a specific safety system: a pre-crash pedestrian system. In parallel with this, APROSYS SP6 (titled "Intelligent Safety Systems") developed a pre-crash side impact system which was also evaluated using the generic methodology [4].

Pre-crash Pedestrian System 'Test Case'

Since a complete system was unavailable, the 'test case' pedestrian safety system consisted of separate sensing and actuator systems fitted to two different vehicles, and as such was a "theoretical" pre-crash pedestrian system. The actuator, was provided in a vehicle front-end developed in the German research project INVENT. The sensing system was from the Daimler PRE-SAFE® Brake/ BrakeAssist Plus system, with a modified decision algorithm to allow this dedicated testing within the project; basically this sensing system was not designed for pedestrian detection.

System Description and Objective - The system assessed was a theoretical pre-crash pedestrian protection system installed on a passenger (M1) vehicle, which uses radar sensors to detect pedestrians in front of the vehicle. When an imminent collision is detected, the actuators in the lower spoiler and bumper are activated to adjust the lower spoiler position and bumper stiffness. In addition, a pop-up bonnet is deployed using the same pre-crash information in order to provide head protection. The overall aim of the system is to reduce pedestrian injury.

The major sensor technologies are: 24 GHz forward looking short and 77 GHz long range radar. The field of view and range of the radar sensors are shown in Figure 2.

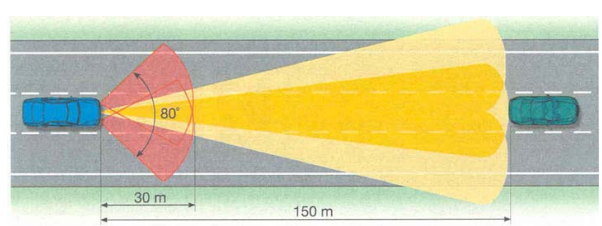


Figure 2. Field of view and range for short range (24 GHz) and long range (77 GHz) radar sensors (Source: Daimler).

The trigger output from the sensing system was displayed using LED indictor lamps fitted to the side of the test vehicle. These included an LED to indicate the trigger signal from the decision algorithm which would be provided to the actuators (had they been fitted on the same vehicle). A second LED was linked to a contact strip on the leading edge of the vehicle's bumper which provided indication of the contact point. These LED indicator lamps are shown in Figure 3.

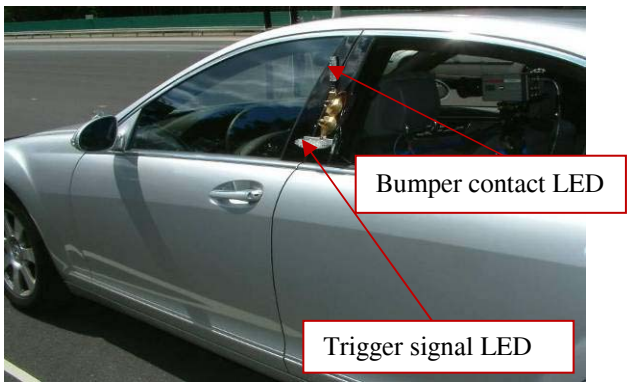


Figure 3. Position of LED indicator lamps for system trigger and bumper contact.

The vehicle front-end consisted of actuators under the bonnet, in the bumper and the lower bumper (Figure 4). The bonnet actuators produced an increase in height at the upper part of the bonnet of about 70 mm. The lower bumper actuator moved the lower bumper 100mm forward and 60 mm downward. The actuator in the bumper can be adjusted in two stages: compliant (0.2 kN) for collisions with pedestrians, and stiff (84 kN) for other impacts. All actuators functioned pneumatically with 12V magnetic valves.

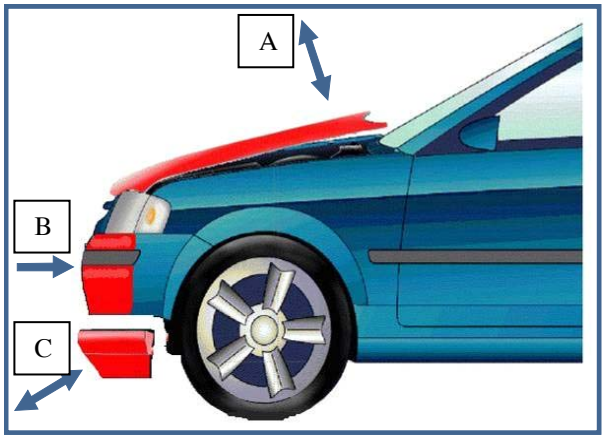


Figure 4. An overview of the actuator systems: pop-up bonnet (A), adjustable bumper stiffness (B), and extendable lower bumper (C) (Source: CSE).

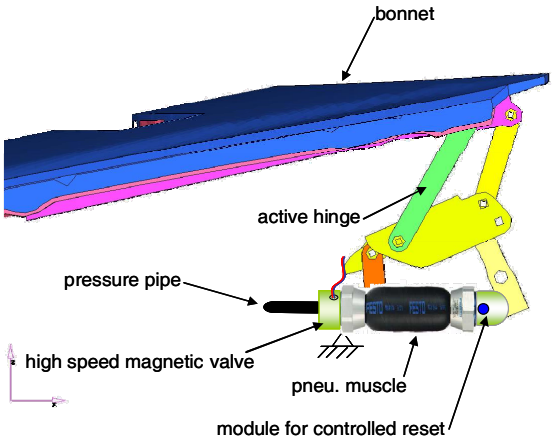


Figure 5: Prototype actuator system for pop-up bonnet (Source: CSE).

Figure 5 shows the basic operation of the actuators in deploying the rear region of the hood.

Application Category - The pre-crash pedestrian system increases the protection offered to pedestrians. It is indented to work in cases where the pedestrian is struck by the front of the vehicle by triggering advanced secondary safety devices on the basis of pre-crash sensing information.

Typical Accident / Traffic Scenarios - Accident scenarios were selected from analysis of the German In-depth Accident Study (GIDAS) database. The data used was not assessed for representativeness of a particular region; the assessment was focussed on the derivation of relevant accident situations.

Within the GIDAS database, selections were made for pedestrian accidents with passenger cars and MPVs. From 1,924 accidents, cases were selected in which the Maximum Abbreviated Injury Scale [3], (MAIS) injury of the pedestrian was AIS 2 or greater. This resulted in 896 accidents, of which 649 accidents related to frontal collisions. This group of accidents were taken as basis for further analysis and were classified into different pedestrian accident types as shown in Figure 6.

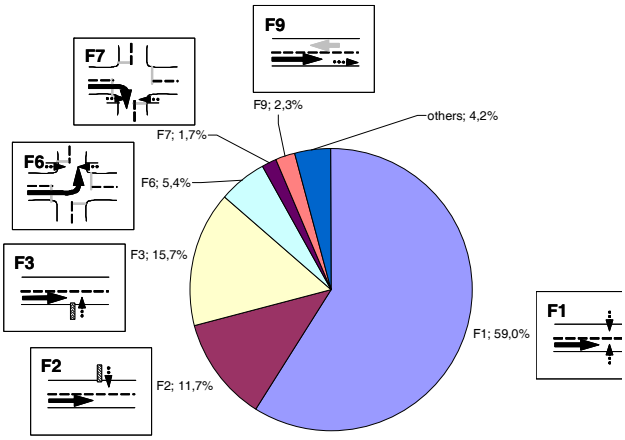
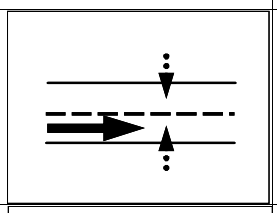
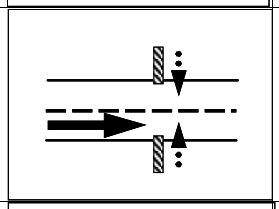
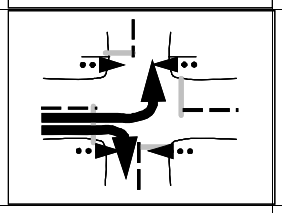


Figure 6. Frontal pedestrian accidents with MAIS 2+ by accident type (GIDAS data).

Using the scenarios illustrated in Figure 6, four main types of pedestrian accident were identified based on the relevance with respect to MAIS 2+ injury. These groups can be seen in Table 1.

Table 1. Scenario groups and their relevance in the GIDAS data

Pedestrian accident type description	Schematic view of pedestrian accident type	Relevance (% of MAIS 2+ pedestrian accidents)
Pedestrian crossing on straight road		59 %
Pedestrian crossing on straight road with occlusion		27.4 %
Pedestrian crossing road shortly after vehicle turning at junction		7.1 %
Others	-	6.5 %

A more detailed analysis was performed on the GIDAS data to derive the ranges of the relevant parameters to be used in the definition of the specific test conditions. The parameters considered are presented in Table 2.

Table 2.
Relevant parameters

Parameter	Description
$V_{vehicle\ initial}$	Vehicle initial velocity
$V_{vehicle\ impact}$	Vehicle impact velocity
$V_{pedestrian}$	Pedestrian velocity
$D_{pedestrian}$	Direction of the pedestrian movement relative to the vehicle (angle)
$X_{vehicle-pedestrian}$	Initial distance between the vehicle and the pedestrian
$Y_{vehicle-pedestrian}$	Initial lateral distance (offset) between the vehicle and the pedestrian
$H_{pedestrian}$	Standing height of pedestrian
D_{object}	Direction of object movement relative to the vehicle (angle)
$X_{object-pedestrian}$	Initial distance between the pedestrian and the object
T_{object}	Type of object obscuring view
$R_{vehicle}$	Turning radius of the vehicle
Light	Light conditions
Weather	Weather conditions
Road	Road condition
Objects	Other surrounding objects

The accident data was analysed to derive relevant ranges for each of the parameters listed in each accident type. The three generic scenarios can be seen in Figure 7 and the ranges for each of the parameters can be found in Table 3.

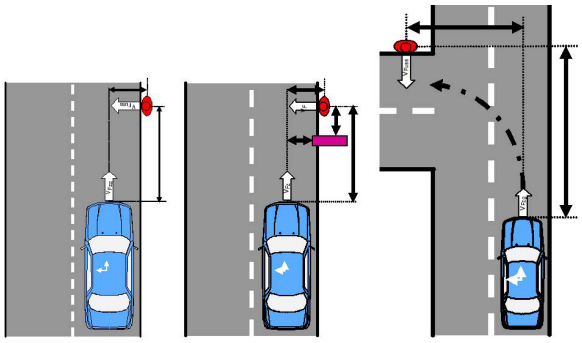


Figure 7. Pre-crash pedestrian test scenarios.

Table 3. Parameters for the pre-crash test scenarios

Parameter	Scenario 1	Scenario 2	Scenario 3
$V_{vehicle\ initial}$ [km/h]	50 ±20	45 ±25	20 ±10
$V_{vehicle\ impact}$ [km/h]	35^{+20}_{-10}	35 ±20	20^{+10}_{-15}
$V_{pedestrian}$ [km/h]	$5.4^{+10.8}_{-3.6}$	$5.4^{+10.8}_{-3.6}$	$5.4_{-3.6}$
$D_{pedestrian}$ [°]	±90	±90	±90
$X_{vehicle-pedestrian}$ [m][1)]	> 20	> 20	> 20
$Y_{vehicle-pedestrian}$ [m][2)]	To be calculated (see note)	To be calculated (see note)	8
$T_{vehicle}$ [-]	Passenger car	Passenger car	Passenger car
$H_{pedestrian}$ [m]	1.7 ± 0.2	1.7 ± 0.2	1.7 ± 0.2
D_{object} [°]	-	Fixed	-
$X_{object-pedestrian}$ [m]	-	0.5	-
T_{object} [-]	-	Parked car / van	-
$R_{vehicle}$ [m]	-	-	6
Environment related parameters			
Light	Day, night	Day	Day, night
Weather	Dry	Dry	Dry
Road	Dry asphalt	Dry asphalt	Dry asphalt
Objects	n/a	n/a	n/a

[1)] Pedestrian initially outside sensor field of view.
[2)] Impact point should be mid-front of the vehicle. The initial offset needed should be derived from the initial distance between the vehicle and the pedestrian and their velocities.

The parallel work conducted by APROSYS SP6 identified that some expert knowledge was necessary to define 'typical' traffic environments relevant for the performance of the sensor system. Consequently, in the APROSYS SP6 evaluation, additional scenarios were defined which were a greater challenge for the sensor system and decision algorithm than those derived from accident data.

Definition of Specific Test Conditions and Assessment Criteria

Pre-crash Performance Tests - Pre-crash tests are required to assess the performance of the sensing system and decision algorithm. These tests are derived from the scenarios defined in box 3, The tests are required to be non-destructive, because performance characterisation of sensor systems is based on statistical performance measures. A series of test scenarios were defined based on the ranges of the parameters listed in Table 3, which involved varying vehicle and pedestrian velocities, test objects travelling from the left and right, and with and without vehicle braking. Each test was repeated up to four times. Other assessments might consider a greater number of tests depending on the statistical significance required.

The pre-crash tests were performed both on a test track (see Figure 8) and in laboratory (see Figure 9).

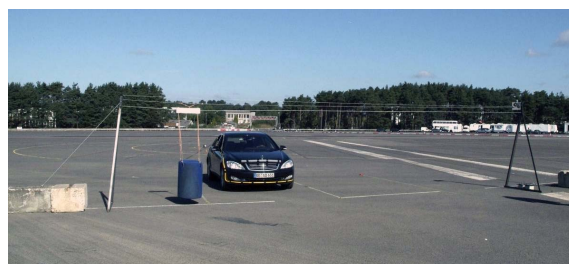


Figure 8. Example track test set up.

Figure 9. Example laboratory test set up.

In order to conduct the track tests, a mechanism was developed so that the test object (a foam cylinder) could be presented into the path of the vehicle at the required velocity and time. A pulley system enabled a small carriage to be driven by a motor calibrated to drive the carriage at the required test speeds. The test object was linked to the carriage via four guide ropes and these were attached with Velcro so that they would detach on impact. The test object was attached so that the bottom edge of the target was in line with the lower spoiler of the test vehicle. The test object was initially positioned off the carriageway marked for the test vehicle. The motion of the test object was triggered by positioning contact sensors on the test

vehicle's approach. These were positioned according to the speed of the test run and whether or not the test configuration involved vehicle braking.

The test results for the track and laboratory tests were analysed by reviewing the high-speed video of each test and determining the time between the trigger signal and first bumper contact. Information on the contact point of the target with the vehicle, assessed by examining the test video was also recorded.

The testing was performed both on a test track (TRL and CSE) and in a laboratory facility (TNO). It was found that both test strategies had strengths and weaknesses; track testing was very flexible and allowed all test configurations to be performed, but controlling all experimental variables proved difficult. Testing in a laboratory environment resulted in excellent control of experimental variables (test velocity and impact site). However, not all of the test scenarios were within the capabilities of the facility, meaning only one test scenario could be assessed.

Crash Performance Tests - Part 1 of EC Directive 2003/102 was chosen to assess the performance of the actuator system. Three head form to bonnet impactor tests: above each actuator and in the middle of the bonnet and two legform impactor tests; mid-vehicle and offset to one side by 427 mm were performed (see Figure 10). Three non-impact deployments were also recorded.

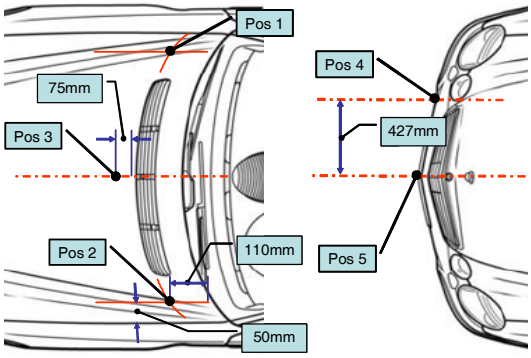


Figure 10. Test sites for headform and legform impacts.

Since the actuator component of the system under assessment was not linked to the sensing and decision algorithm, a synthetic trigger was provided to the vehicle front end 160 ms before impactor contact. The intention of these tests was that the actuators should be 'in function' directly before the impact of lower-leg or head-impactor. In a 'real' assessment, the information on the measured sensing performance would be used as an input to these tests; however, in this test case, the sensing systems was assumed to work as intended and provide a trigger signal to the actuators 160ms prior to impact.

Figure 11. Example actuator tests

Testing was performed by both TRL and CSE; this demonstrated successful pre-triggering of the actuators of a pre-crash pedestrian system to co-ordinate with existing headform and legform test.

Driver-in-the-Loop Performance Tests - In order to investigate the actuator systems whose activation in either the pre-crash or false triggering events might influence safety, "driver in the loop" tests were devised. These were carried out in the Daimler driving simulator and aimed to assess reaction of the driver and the effect on safety during "crash" or "no-crash" conditions.

In the test case, driver reactions to a pre-crash pedestrian protection system (pop-up hood) were investigated and evaluated for various driving circumstances and hazard situations. The main focus was to compare behaviour in a pedestrian impact event ("true") with that of a false activation ("false") and a "reference event"; a realistic event with which to compare the effect on the driving task. These events assessed are shown in Figure 12.

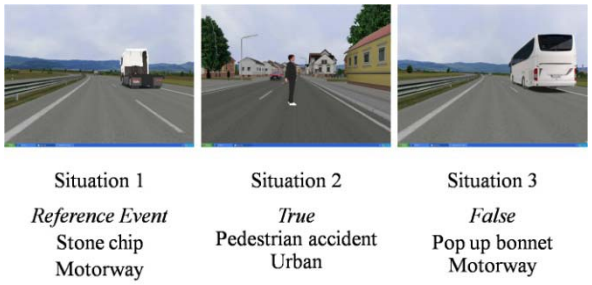


Figure 12. Scenarios defined and tested for "driver in the loop" testing of a pop-up bonnet.

The tests were carried out in the Daimler AG dynamic driving simulator using a total of 44 test subjects. Changes in the lateral dynamics (steering angle) and longitudinal dynamics (speed) during each event were recorded. Small, oscillating steering or "control" movements made by the driver (steering entropy), were used as a measure of the level of mental stress, since this has been proposed as a suitable measure for this parameter [5]. The results are shown in Figure 13.

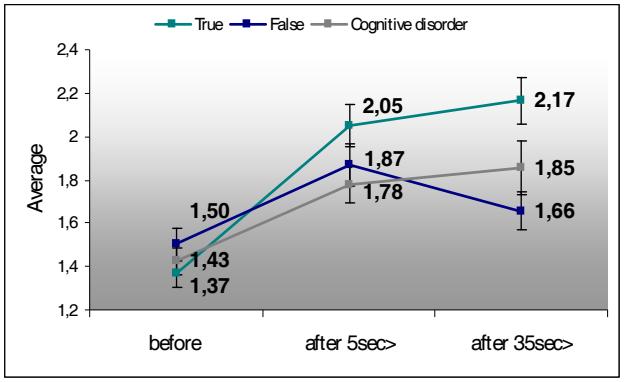


Figure 13. Steering entropy before and after each event.

In all events, the steering entropy increased noticeably after each event, indicating increased driver stress. The increase was greatest and longer-lasting for the pedestrian impact event ("true"). The false trigger event ("false") was similar to the reference event in terms of the effect on mental stress. Ultimately, and in relation to these parameters, no increased risk in managing the task of driving was observed in the driving scenarios chosen here. Subjective evaluation via subject interviews confirmed the objective data and allowed the false activation event to be compared to both a pedestrian impact and a reference event.

Relevant Supporting Information - No relevant supporting information was produced as part of the test case assessment for the pedestrian pre-crash system. However, APROSYS SP6 developed an advanced side impact protection system which used pre-crash radar and video sensing to detect side collisions. SP6 devised a field test to measure sensor performance under normal driving conditions. A route of about 3,000km was selected, comprising different road types, driving conditions and traffic. It was found to be a successful method to collect data on the numbers of false activations in normal traffic.

DISCUSSION

The generic methodology has been developed as a framework which can be applied to a range of advanced systems, and used by a range of stakeholders. For example, it is intended that the guidelines may be used by industry, regulators, or by consumer testing organisations. These stakeholders will apply the methodology with different end goals. For example, the methodology might be used as a basis for regulatory tests to ensure a minimum level of performance and to ensure that risks are adequately controlled. If this is the case, then information supplied via box 6 by OEMs or suppliers might be considered a requirement to demonstrate the performance of the system in a wider range of conditions than can be tested in box 5.

Related to the application of the methodology is whether the tests developed under this framework are in addition to the existing secondary safety requirements, or if the performance assessment could replace existing requirements. For example, if a system includes an automatic braking function and the sensing system can be shown to work as intended, this will result in a reduced impact speed. The generic methodology developed here assesses the performance of the system and the crash evaluation is carried out in line with the pre-crash performance (i.e. conducted at a reduced impact speed). Indeed, this is essential to fully assess the performance at the system and to allow the casualty benefit of the system to be estimated. However, this approach is not incompatible with the current regulatory or consumer testing regimes, as the tests developed from this methodology can be viewed as additional to existing requirements.

For some integrated systems, there may be actuators which utilise the same sensors but react to different trigger signals from the decision-making algorithm. Should a vehicle be equipped with systems which address more than one application category, this results in the derivation of different relevant test conditions (and target populations) being defined. This may result in more than one test suite (pre-crash, crash, driver in the loop) being performed since the generic methodology is system-focussed.

The accident data used to define the relevant accident scenarios is a critical component to ensure that the tests derived are representative of the appropriate accident conditions. The scope of the data required is to some extent dependent on the purpose of the application of the methodology. Furthermore, it seems unlikely that a European data source

containing information at the required level of detail will be available. Therefore, the accident data used as an input to the methodology is likely to remain a combination of representative national data and more detailed in-depth information. The generic methodology provides guidance regarding how the accident data should be used.

The generic methodology does not specify the number of test scenarios or the number of repeats of each test. It is not possible to specify these, since the methodology is generic, and therefore the range of relevant accident scenarios for each system depends on the system. However, the number of repeats should be such that adequate representation of the pre-crash and crash performance can be achieved. Since sensing system for different systems might be set at different levels of sensitivity, depending how "safety critical" the activation is, the number of repeat tests required to characterise the performance is also system dependent. However, the number of tests should be such that as close to 100% of the target population as possible is considered. Furthermore, the number of repeat tests for each test scenario may also depend on how the methodology is being used, but should be such that the performance of the sensor is appropriately accounted for. Ultimately, the required level of confidence required in the results is dependent on the stakeholder and the type of evaluation being undertaken.

The final methodology does not provide detailed specifications for the "driver in the loop" study. However, the pedestrian pre-crash system test case devised a series of simulator events designed to evaluate driver response between true (pre-crash), false (false triggering) and a reference event (realistic driving hazard). This approach was successful in comparing the response of the driver in these situations. Assessment of the effect of the system on the driver was successfully assessed in a driving simulator and this was shown to be an appropriate tool for this purpose.

The principle of measuring the long-term effects of advanced safety systems is important, and may be applied by stakeholders depending on the scope of the assessment. Specifications for field operational tests exist [6] and these may be used to provide requirements for the information supplied via this step of the methodology.

The overall assessment is dependent on the application of the methodology and also on the specific system being assessed. It is envisaged that the results from the technical performance could be integrated to formulate an overall rating scheme, similar to the system used by EuroNCAP. The methodology is also capable of being used to provide an estimate of the casualty-saving potential of the system. This would be achieved by considering the proportion of all casualties accounted for by the accident types derived from step 3 (real world accident data). The performance of the system in the tested accident types would provide performance information to estimate the effect of the system on this group of casualties. The type of overall assessment made is dependent on the stakeholder carrying out the evaluation and the purpose of the evaluation.

CONCLUSIONS

This paper presents the final APROSYS generic methodology for active safety systems. This methodology is intended to be applicable to a wide range of advanced safety systems and describes the different steps that should be taken in the development of a performance evaluation protocol for a specific advanced safety system. The flowchart providing an overview of the methodology is shown in Figure 1. The generic methodology is also designed to be flexible such that it can be used by a wide variety of stakeholders, from consumer organisations, legal authorities and industry, all of whom have a need to evaluate the technical performance of pre-crash safety systems. The main conclusions can be summarised as follows:

- The application of the methodology within the APROSYS project showed that relevant accident scenarios could be identified and transferred to appropriate test conditions. The test procedures developed from the methodology allowed the systems to be evaluated in terms of the pre-crash, crash and driver-in-the-loop performance.

- The generic methodology focuses on developing testing for a specific system to evaluate the system performance. This testing can be applied in addition to existing regulatory and assessment procedures.

- Stakeholders should ensure that the tests as accurately as possible represent the target population (those accidents influenced by the system) and that a sufficient number of repeat tests are performed to characterise system performance; what constitutes this threshold depends on the application of the methodology. A specific test programme

should define requirements for valid tests and suitable means of monitoring the key parameters (such as vehicle speed) to ensure that any testing is repeatable.

- The test conditions developed during the APROSYS testing were highly simplified with relation to the road environment as seen by the sensing system. This indicates that, depending on the specific system under assessment and the purpose of the assessment, relevant supporting information on the "real world" performance of the sensing system may be important. This would assess the pre-crash performance in a wider range of situations than defined in any assessment tests.
- Expert knowledge has been permitted by the methodology to supplement situations derived from accident data, in order to represent typical environmental conditions which cannot be defined from existing data.
- Pre-crash tests were carried out using track and laboratory facilities; both these approaches had strengths and weaknesses. The pre-crash testing carried out on a test track was found to be very adaptable in that all of the relevant test types could be successfully represented on the test track. However, although flexible in terms of the types of test configurations, it was found that achieving a "valid test" – one in which the vehicle struck the test object correctly at the correct speed was affected by small variations in vehicle or target velocity and/or braking level. In contrast, testing in laboratory facilities proved to be very repeatable; however, only one test scenario could be tested in this facility. This suggests a need for a "virtual laboratory" approach, comprising several facility types.
- The overall assessment should be developed by the stakeholder, depending on the purpose of the assessment and the system being assessed. The assessment can be made in terms of the performance of the system within those accident types assessed and/or in terms of the estimated casualty reduction potential of the system.

ACKNOWLEDGEMENTS

The author acknowledges the contribution of the members of the APROSYS 1.3 consortium to this paper:

- BASt, Germany
- Continental, Germany
- Daimler AG, Germany
- TNO, Netherlands
- TRL, UK
- Volkswagen, Germany

The close co-operation with APROSYS SP6 partners is also acknowledged. For more information on the APROSYS project and project deliverables, please refer to www.aprosys.com.

The consortium is grateful for the support of: the European Commission DG-TREN, UK Department for Transport, German Ministry of Transport and Housing, and the Dutch Ministry of Transport for funding this work.

REFERENCES

[1] McCarthy, M., Lange, R. de, Lemmen, P. (2006), Review of Regulations and Research regarding Advanced Safety Functions, Deliverable D1.3.1, *APROSYS Document AP-SP13-0011*.

[2] OICA/CLEPA (2005), Certification Standard for Type Approval Testing of Active Deployable Systems of the Bonnet / Windscreen Area, *Draft document INF GR PS 141*.

[3] AAAM (2008). Abbreviated Injury Scale (AIS) 2005 – Update 2008. Association for the Advancement of Automotive Medicine, 2340 Des Plaines Avenue, Suite 106, Des Plaines, Illinois 60018, USA.

[4] APROSYS deliverable D6.5.4 Evaluation of test methods / recommendations for a generic test suite. *APROSYS Document AP-SP65-0055*.

[5] Nakayama, O., and Nakamura, T. (1999). Development of a steering entropy method for evaluating driver workload. *SAE transactions* 1999, vol. 108 (1), 6, pp. 1686-1695.

[6] FESTA (2008). 7thFP ICT Project; FESTA Handbook Draft Version 25th April 2008; www.its.leeds.ac.uk/festa/index.php

© Copyright TRL Limited 2009.