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Detailed draft test scenarios for a specific pre-crash safety system

Deliverable report

Deliverable 1.3.3

AP-SP13-0035-D133-Generic Test Methods

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<th>Approved by</th>
<th>Visa</th>
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<td>Mike McCarthy (TRL)</td>
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Leading company: TNO
Publishable summary

The European Framework Programme Integrated Project (IP) on Advanced Protection Systems (APROSY) focuses on developments in the field of vehicle safety. Sub-project 1 (SP1), titled ‘Car Accidents’, investigates the development and validation of evaluation methods and advanced protection systems. The aim is to reduce the number of car occupant fatalities and serious injuries by developing test procedures which will improve the protection offered by cars.

Within Work package 1.3 (WP1.3), titled ‘Advanced safety functions’, the focus is the development of an assessment methodology for adaptive safety devices that employ pre-crash information from environmental sensor systems. Within Task 1.3.1 the existing methods and relevant literature have been reviewed and in Task 1.3.2 a draft generic evaluation method has been developed. Within the current task (Task1.3.3) the generic evaluation methodology is evaluated by using this methodology to assess an advanced pedestrian protection system.

In this report, the generic evaluation methodology has been used to develop a system specific assessment plan for the selected advanced pedestrian protection system. This system consists of a 24 GHz short range radar sensor-cluster triggering a pop-up bonnet, a bumper with switchable stiffness properties and a moveable lower bumper. Based on the system specifications and the application category, an accidentology study has been performed to categorise real world accident scenarios and their relevance to the casualty population. As a next step test conditions have been developed for:

- The assessment of the pre-crash performance.
  - The test conditions are based on the most important real world accident scenarios. In total 13 test conditions have been defined related to three generic scenarios. The number of test conditions related to each scenario does reflect the real world relevance of each scenario;
- The assessment of the crash performance.
  - Existing test procedures as specified in Directive 2003/102/EC are used for this evaluation. Head form tests have been specified to evaluate the pop-up bonnet and leg form tests evaluate the switchable bumper stiffness and the moveable lower bumper;
- The assessment of the human behaviour.
  - In a moving base driving simulator the driver reactions upon a pop-up bonnet is evaluated in both crash and false alarm situations. These tests will also indicate the suitability of a driving simulator as tool for use in the evaluation procedure.
- The assessment of the system performance in real world traffic conditions.
  - This performance is estimated in a numerical study using PreScan software. The sensor and decision algorithm are modelled and applied numerically in a wide range of crash situations. This study links to the assessment procedure via the relevant supporting information box.

The evaluation results will be used together with the results from APROSY WP6.5, to review and refine the generic evaluation methodology. In addition, this work is linked to APSN sub objective 1.2 where the WP1.3 activities serve as a pilot case for sharing of facilities.
Acknowledgement

Following participants contributed to this deliverable report.

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<td>Thomas Wohllebe</td>
<td>3 &amp; 4</td>
</tr>
<tr>
<td>Siemens Restraint Systems</td>
<td>Johannes Vetter</td>
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<td>Daimler Chrysler</td>
<td>Christian Mayer</td>
<td>3 &amp; 4 + review</td>
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<td>TRL</td>
<td>Mike McCarthy</td>
<td>review</td>
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<tr>
<td>TNO</td>
<td>Ronald de Lange</td>
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1 Introduction

The European 6 Framework Programme Integrated Project (IP) on Advanced Protection Systems (APROSYS) focuses on developments in the field of vehicle safety. Sub-project 1 (SP1), titled ‘Car Accidents’, investigates the development and validation of evaluation methods and advanced protection systems. The aim is to reduce the number of car occupant fatalities and serious injuries by developing test procedures which will improve the protection offered by cars.

Within Work package 1.3 (WP1.3), titled ‘Advanced safety functions’, the focus is on the development of evaluation methods for the assessment of adaptive safety devices that employ pre-crash information from environmental sensor systems. Within Task 1.3.1 the existing methods and relevant literature have been reviewed and in Task 1.3.2 a draft generic evaluation method has been developed. Within the current task (Task 1.3.3) the generic evaluation methodology is evaluated by using this methodology to assess a specific system. The system to be evaluated is an experimental pre-crash pedestrian protection system.

The main aims for the evaluation of the pre-crash pedestrian protection system are to:

- check the feasibility of the generic assessment method and to define potential improvements;
- investigate the appropriateness of different testing approaches, especially for the evaluation of the pre-crash and the driver-in-the-loop performance.

This document describes the draft specific evaluation plan for the pre-crash pedestrian protection system. The draft assessment methodology is described in chapter 2. According to the method, a system description and relevant accident scenarios are provided in chapter 3. In chapter 4 the test conditions are given, based on the relevant scenarios derived from the accident data. The chapters 5 and 6 comprise a discussion, the conclusions and recommendations.
2 Generic methodology

The generic assessment methodology used here has been developed in task 1.3.2 of APROSYS WP1.3. In this methodology, which is applicable to a wide range of advanced safety systems, the system is considered from an end-users point of view. It describes the different steps that have to be taken to evaluate an advanced safety system. The flowchart describing the methodology is shown in Figure 1.

Figure 1: Flowchart of the APROSYS WP1.3 generic evaluation methodology
In general, the generic evaluation methodology is characterised by a partition of the holistic evaluation process into three assessment clusters:

- pre-crash performance, based on statistical accident data and real world data;
- crash performance;
- normal driving performance.

As can be seen in Figure 1, the Boxes 1 to 4 describe the system itself, its technology, its field of application and the system objective. In Box 5, the accident and/or traffic scenarios from Box 3 are used to develop system specific test conditions resulting in a test plan for the assessment of the pre-crash, the crash and, if necessary, the driver-in-the-loop behaviour (Box 6a, 6b and 6c, respectively). Additional information, for instance about the real world performance of the system, can be provided via Box 7. For further details the reader is referred to [1].
3 Specific methodology for pre-crash pedestrian protection system

3.1 Introduction

Based on the generic assessment methodology, the boxes from the flowchart are expanded in detail for the advanced pedestrian protection system which is used to evaluate the methodology.

3.2 System description (Box 1)

The system description is a brief description of the product or function to be evaluated.

Application name and type

The application of the advanced safety system under evaluation is a pedestrian protection system. Critical situations with pedestrians are recognised by exterior sensors, and if a collision with a pedestrian is judged as unavoidable, the actuators in the lower bumper, the bumper and the bonnet are activated to adjust the lower bumper and bonnet position and the bumper stiffness.

Major technologies whose application is under validation

Sensing system - The sensor cluster of the pre-crash system consists of two 24 GHz short range radar sensors. The position of both radar sensors can be seen in Figure 2 and the sensor field of view is indicated by the red field in Figure 3. The short range radar sensors are mounted behind the bumper at 36 cm offset from mid vehicle. The horizontal opening angle of each sensor is about 40 degrees and the distance range is about 30 m. The total horizontal opening angle of the short range radar cluster is about 80 degrees.

Figure 2: The experimental vehicle with the sensor locations (in green)
Figure 3: The sensor field of view for the 2 short range radar sensors (in red) and the long range radar (in yellow; not used for the pedestrian protection application) (Source: Daimler Chrysler).

The sensor cluster has been derived from a serial-production application but is currently used in a prototypical / research pre-crash system environment. A modified algorithm / decision unit generates an ‘actuator fire’ trigger preferably at 200 ms time-to-collision (TTC) when relevant objects are detected and tracked. However, a trigger will be provided also by the system if objects are recognised later than 200 ms time-to-collision. Depending on the estimated time before the impact that the trigger is given, the strategy for firing the actuators is as follows:

- between 240 ms and 160 ms before the impact, all three actuators will be fired (moveable lower bumper, switchable bumper stiffness and deployable bonnet);
- between 160 ms and 100 ms before the impact the switchable bumper stiffness and deployable bonnet will be activated;
- between 100 ms and 60 ms before the impact the switchable bumper stiffness will be activated;

It should be noted that the vehicle to be evaluated is equipped with various other advanced safety functions (e.g. autonomous braking) and sensors (e.g. additional to the two short range radar sensors, also a 77 GHz long range radar sensor is mounted on the vehicle) related to the Mercedes PRE-SAFE® system and the ACC-system. The long range radar sensor will NOT trigger any of the autonomous vehicle functions and is not used by the pre-crash pedestrian protection system. However, the BAS+ (Brake Assist +) system, using the 24 GHz and the 77 GHz sensors, is active. This means that when relevant crash objects are detected by the sensor system and the driver starts to brake full braking will be applied by the car, even if the driver does not apply full braking.

**Actuator system** - The actuator fire trigger activates the actuators under the bonnet, in the bumper and the lower bumper (Figure 4). The bonnet actuators raise the bonnet such that the rear part of the bonnet lifts for about 70 mm. The lower bumper actuator moves the lower bumper about 100 mm 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 are reversible and work pneumatically with 12V magnetic valves.
Figure 4: An overview of the actuator systems. The bonnet actuator (a), the bumper actuator (b), the lower bumper (c) and the overview (d) (Source: Siemens Restraint Systems).

**Functionality or service offered**

The pre-crash pedestrian protection system is able to detect impending pedestrian collisions with the vehicle front. Based on this information the bonnet is deployed, the bumper is made more compliant and the lower bumper is moved forward and downward. Thus, the vehicle front is made more compliant to a pedestrian and the injury severity of the impacted pedestrian is reduced.

**System limitations**

The system is active in a velocity range from 17 km/h (lower limit) up to 50 km/h (upper limit) impact velocity. Below 17 km/h the impact energy is assumed to be too low and activation of the bonnet, bumper and lower bumper actuators will have no significant effect on the injury severity. Above 50 km/h, the impact is assumed to be too severe and the pedestrian protection system will have no significant mitigating effect.

### 3.3 Application category (Box 2)

The application category defines the field of application of the safety system and the road users that are protected.

The safety system considered here is a forward looking pre-crash pedestrian protection system implemented on a passenger vehicle. The road users protected are pedestrians.

### 3.4 Typical accident / traffic scenarios (Box 3)

For the definition of the typical accident scenarios various sources have been reviewed:

- a study performed within the SAVE-U project [2];
- a study performed within the COMPOSE sup project of PReVENT [3];
- a study also based on the GIDAS data performed within the INVENT project [4].

As a lack of information was found in all three available studies, an additional analysis was performed within APROSYS WP1.3 using the GIDAS accident database. This analysis has been used for the definition of the typical accident scenarios.
Within the GIDAS database selections were made for pedestrian accidents with passenger cars and MPV’s. An overview of the accident scenarios, based on 1924 cases can be found in Appendix A. From these 1924 accidents the cases were selected in which the injury level of the pedestrian was MAIS 2+. This resulted in 896 accidents included of which 649 accidents related to frontal collisions. Those accidents were assumed representative and were taken as basis for further analysis. A separation into the most relevant scenarios resulting in the scenarios as can be seen in Figure 5.

![Figure 5: Frontal pedestrian accidents with MAIS 2+, scenario selection on initial conflicts.](image)

Using the scenarios as given in Figure 5 as a basis, four groups of scenarios were developed. These groups can be seen in Table 1.
Table 1: Scenario groups and their relevance resulting from the GIDAS analysis

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Schematic view</th>
<th>Relevance</th>
<th>Remark</th>
</tr>
</thead>
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<tr>
<td>1. Crossing pedestrian on straight road</td>
<td><img src="image" alt="Schematic" /></td>
<td>59 %</td>
<td>Scenario F1</td>
</tr>
<tr>
<td>2. Crossing pedestrian on straight road with occlusion</td>
<td><img src="image" alt="Schematic" /></td>
<td>27.4 %</td>
<td>Scenarios F2 and F3</td>
</tr>
<tr>
<td>3. Crossing pedestrian after turn off</td>
<td><img src="image" alt="Schematic" /></td>
<td>7.1 %</td>
<td>Scenarios F6 and F7</td>
</tr>
<tr>
<td>4. Others</td>
<td>-</td>
<td>6.5 %</td>
<td></td>
</tr>
</tbody>
</table>

In addition a more detailed analysis was performed on the GIDAS data to derive the ranges of relevant parameters to be used in the definition of the specific test conditions, like for instance impact velocity. The results of this more detailed analysis can be found in Appendix A.

### 3.5 System objective (Box 4)

The system objective describes the main objective of the safety system to be evaluated.

The aim of the developed pre-crash pedestrian protection system is to reduce the injury risk of vulnerable road users during collisions between the vehicle front-end and the pedestrian. This will be done by an increased compatibility between the vehicle front-end and the pedestrian. More specifically:

- the lifted bonnet will protect the head (and thorax area) of the pedestrian;
- the bumper and lower bumper do protect the leg and knee of the pedestrian.
4 Definition of specific test conditions and assessment criteria (Box 5)

Below the test conditions and assessment criteria have been defined according to Box 5 of the generic evaluation methodology. This has been done for the pre-crash assessment, for the crash assessment and for the driver-in-the-loop performance and is used as input for Box 6.

4.1 Pre-crash performance

4.1.1 Test scenarios

Based on the three groups of accident scenarios as defined in Table 1, three generic scenarios were developed. For those scenarios the parameters as provided in Table 2 were identified as relevant parameters for the 3 generic scenarios:

<table>
<thead>
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<th>Table 2: Relevant parameters</th>
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<tr>
<td>Parameter</td>
</tr>
<tr>
<td>------------------------------</td>
</tr>
<tr>
<td>V&lt;sub&gt;vehicle initial&lt;/sub&gt;</td>
</tr>
<tr>
<td>V&lt;sub&gt;vehicle impact&lt;/sub&gt;</td>
</tr>
<tr>
<td>V&lt;sub&gt;pedestrian&lt;/sub&gt;</td>
</tr>
<tr>
<td>D&lt;sub&gt;pedestrian&lt;/sub&gt;</td>
</tr>
<tr>
<td>X&lt;sub&gt;vehicle-pedestrian&lt;/sub&gt;</td>
</tr>
<tr>
<td>Y&lt;sub&gt;vehicle-pedestrian&lt;/sub&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;vehicle&lt;/sub&gt;</td>
</tr>
<tr>
<td>H&lt;sub&gt;pedestrian&lt;/sub&gt;</td>
</tr>
<tr>
<td>D&lt;sub&gt;object&lt;/sub&gt;</td>
</tr>
<tr>
<td>X&lt;sub&gt;object-pedestrian&lt;/sub&gt;</td>
</tr>
<tr>
<td>Y&lt;sub&gt;vehicle-pedestrian&lt;/sub&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;object&lt;/sub&gt;</td>
</tr>
<tr>
<td>R&lt;sub&gt;vehicle&lt;/sub&gt;</td>
</tr>
<tr>
<td>------------------------------</td>
</tr>
<tr>
<td>Light</td>
</tr>
<tr>
<td>Weather</td>
</tr>
<tr>
<td>Road</td>
</tr>
<tr>
<td>Objects</td>
</tr>
</tbody>
</table>

The accident data has been analysed to derive the relevant range of the listed parameters for each of the generic scenarios. The three scenarios can be seen in Figure 6 and the parameters with typical values can be found in Table 3.
Scenario 1: Crossing pedestrian on straight road

Scenario 2: Crossing pedestrian on straight road with occlusion

Scenario 3: Crossing pedestrian after turn off
Figure 6: The generic accident scenarios

Table 3: Parameters for the generic accident scenarios

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
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<tr>
<td>V_{vehicle} [km/h]</td>
<td>50 ±20</td>
<td>45 ±25</td>
<td>20 ±10</td>
</tr>
<tr>
<td>V_{vehicle impact} [km/h]</td>
<td>35 ±20</td>
<td>35 ±20</td>
<td>20 ±10</td>
</tr>
<tr>
<td>V_{pedestrian} [km/h]</td>
<td>5.4 ±10.8 -3.6</td>
<td>5.4 ±10.8 -3.6</td>
<td>5.4 ±10.8 -3.6</td>
</tr>
<tr>
<td>V_{object} [km/h]</td>
<td>-</td>
<td>n/a</td>
<td>-</td>
</tr>
<tr>
<td>D_{pedestrian} [°]</td>
<td>±90</td>
<td>±90</td>
<td>±90</td>
</tr>
<tr>
<td>X_{vehicle-pedestrian} [m]</td>
<td>&gt; 20</td>
<td>&gt; 20</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>Y_{vehicle-pedestrian} [m]</td>
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<td>to be calc.</td>
<td>8 (6 + 2)</td>
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<tr>
<td>T_{vehicle} [-]</td>
<td>passenger car</td>
<td>passenger car</td>
<td>passenger car</td>
</tr>
<tr>
<td>H_{pedestrian} [m]</td>
<td>1.7 ± 0.2</td>
<td>1.7 ± 0.2</td>
<td>1.7 ± 0.2</td>
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<tr>
<td>D_{object} [°]</td>
<td>-</td>
<td>Fixed</td>
<td>-</td>
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<tr>
<td>X_{object-pedestrian} [m]</td>
<td>-</td>
<td>0.5</td>
<td>-</td>
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<tr>
<td>Y_{vehicle-object} [m]</td>
<td>-</td>
<td>n/a</td>
<td>-</td>
</tr>
<tr>
<td>T_{object} [-]</td>
<td>-</td>
<td>parked car / van</td>
<td>-</td>
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<tr>
<td>R_{vehicle} [m]</td>
<td>-</td>
<td>-</td>
<td>6</td>
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Environment related parameters

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<td>dry</td>
<td>dry</td>
</tr>
<tr>
<td>Road</td>
<td>dry asphalt</td>
<td>dry asphalt</td>
<td>dry asphalt, wet asphalt</td>
</tr>
<tr>
<td>Objects</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

1 Pedestrian should be 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 the velocities of the vehicle and the pedestrian.
4.1.2 Assessment criteria

For each specific scenario, the pre-crash performance is good if the system is activated in time in an impact between the pedestrian and the vehicle. Therefore the system-in-function time is the most suitable assessment criterion or key indicator to be measured. The system-in-function time could be measured for instance by monitoring the state of the actuators. The system-in-function time could than be defined as the time the actuators are fully deployed related to the start of the impact. However, since the vehicle used for the pre-crash performance tests is an experimental vehicle equipped with the sensing system and not with the actuators, it is not possible to measure the system-in-function time. Therefore the ‘actuator fire’ trigger that is given by the system will be displayed with an indicator lamp on the dashboard (this will be comparable to the original COMPOSE vehicle installation).

Additionally, the actuator times have been assumed. The times needed for a full activation of the different actuators are:

- 190 ms for a fully activated bonnet;
- 100 ms for a fully activated lower bumper;
- 60 ms for a fully activated bumper.

The required system-in-function time for the deployable bonnet has been derived from a simulation study. A number of simulations have been performed with the MADYMO human pedestrian models and a model of the Chrysler Neon frontend. Different sized pedestrian models are used ranging from a 6-year-old child to a 95th percentile male and different stances are simulated. An overview of the simulations performed can be seen in Appendix C. From these simulations it was observed that the minimum contact time between the bonnet and the head of the pedestrian is 30 ms after the first contact between pedestrian and vehicle. Therefore, the required system-in-function time, expressed in time-to-collision is set to -30 ms (30 ms after the start of the collision). Both other protective devices (the switchable bumper and the moving lower bumper) have to be deployed at the moment of first contact between the pedestrian and the vehicle. Thus the required system-in-function for these protective devices is set to 0 ms.

Based on the required system-in-function time and the actuator times, the expected required actuator fire trigger time is calculated using the following equation:

\[ T_{\text{trigger}} = T_{\text{system}} - T_{\text{actuator}} \]

With:

- \( T_{\text{trigger}} \) = time the actuator fire trigger signal is given to the actuator;
- \( T_{\text{system}} \) = total system-in-function time;
- \( T_{\text{actuator}} \) = time needed to activate the actuator.

The calculated expected minimum required actuator fire trigger times for the 3 protective devices, expressed in time-to-collision, are:

- 160 ms TTC for the deployable bonnet;
- 100 ms TTC for the moveable lower bumper;
- 60 ms TTC for the switchable bumper.

In case the actuator fire trigger is provided earlier then or equal to 160 ms time-to-collision \((TTC \geq 160 \text{ ms})\), the all protective devices could be activated in time and the test is passed. If the trigger is provided later then 60 ms time-to-collision \((TTC < 60 \text{ ms})\) none of the protective devices could be activates in time and the test is not passed. If the trigger is provided between 160 and 60 ms time-to-collision, the test is passed only for the protective devices that could be activated in time.
4.1.3 Test conditions

From the accident data shown in Table 1, Table 2 and Table 3 test conditions have been defined. Table 4, Table 5 and Table 6 show the test conditions derived from accident scenario 1, 2 and 3 respectively. The number of test conditions per scenario does relate to the relevance of the accident scenario according to the amount of accidents with MAIS 2+ injuries. The test conditions comprise both relatively simple scenarios with linear motions and constant velocities to more complex scenarios with non-linear motions or full braking applied to reduce the vehicle velocity to the impact velocity at the moment of impact.

Table 4: Pre-crash test conditions derived from accident scenario 1

<table>
<thead>
<tr>
<th>Test condition</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
<th>1.6</th>
<th>1.7</th>
<th>1.8</th>
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<td>$V_{\text{vehicle initial}}$ [km/h]</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>70</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>70</td>
</tr>
<tr>
<td>$V_{\text{vehicle impact}}$ [km/h]</td>
<td>30</td>
<td>35</td>
<td>50</td>
<td>50</td>
<td>30</td>
<td>35</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>$V_{\text{pedestrian}}$ [m/s]</td>
<td>1.5</td>
<td>1.5</td>
<td>4.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>4.5</td>
<td>1.5</td>
</tr>
<tr>
<td>$D_{\text{pedestrian}}$ [°]</td>
<td>+90°</td>
<td>+90°</td>
<td>+90°</td>
<td>-90°</td>
<td>-90°</td>
<td>-90°</td>
<td>-90°</td>
<td>-90°</td>
</tr>
<tr>
<td>$X_{\text{vehicle-pedestrian}}$ [m]</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>
| $Y_{\text{vehicle-pedestrian}}$ [m] | calc.| calc.| calc.| calc.| calc.| calc.| calc.| calc.| 20
| $T_{\text{vehicle}}$ [°]          | pc  | pc  | pc  | pc  | pc  | pc  | Pc  | pc  |
| $H_{\text{pedestrian}}$ [m]       | 170 | 170 | 170 | 170 | 170 | 170 | 170 | 170 |
| Pre-crash action [-]             | -   | full brake | - | full brake | - | full brake | - | full brake |

1) calc. = to be calculated from the initial X-distance between the pedestrian and the vehicle, the velocities and the impact point. 2) pc = passenger car.

Table 5: Pre-crash test conditions derived from accident scenario 2

<table>
<thead>
<tr>
<th>Test condition</th>
<th>2.1</th>
<th>2.2</th>
<th>2.3</th>
<th>2.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{vehicle initial}}$ [km/h]</td>
<td>45</td>
<td>70</td>
<td>45</td>
<td>70</td>
</tr>
<tr>
<td>$V_{\text{vehicle impact}}$ [km/h]</td>
<td>35</td>
<td>50</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td>$V_{\text{pedestrian}}$ [m/s]</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>$V_{\text{object}}$ [m/s]</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$D_{\text{pedestrian}}$ [°]</td>
<td>+90°</td>
<td>+90°</td>
<td>-90°</td>
<td>-90°</td>
</tr>
<tr>
<td>$D_{\text{object}}$ [°]</td>
<td>fixed</td>
<td>fixed</td>
<td>fixed</td>
<td>fixed</td>
</tr>
<tr>
<td>$X_{\text{vehicle-pedestrian}}$ [m]</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>$X_{\text{object-pedestrian}}$ [m]</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
| $Y_{\text{vehicle-pedestrian}}$ [m] | calc.| calc.| calc.| calc.| 20
| $Y_{\text{vehicle-object}}$ [m] | 1m +1/2 vehicle width | 1m +1/2 vehicle width | 2.5m+1/2 vehicle width | 2.5m+1/2 vehicle width |
| $T_{\text{vehicle}}$ [-]          | pc  | pc  | pc  | Pc  |
| $H_{\text{pedestrian}}$ [m]       | 170 | 170 | 170 | 170 |
| $T_{\text{object}}$ [-]           | van | van | van | van |
Pre-crash action [-] | full brake | full brake | full brake | full brake
--- | --- | --- | --- | ---

1) calc. = to be calculated from the initial X-distance between the pedestrian and the vehicle, the velocities and the impact point.
2) pc = passenger car.

Table 6: Pre-crash test condition derived from accident scenario 3

<table>
<thead>
<tr>
<th>Test condition</th>
<th>3.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{vehicle initial}}$ [km/h]</td>
<td>20</td>
</tr>
<tr>
<td>$V_{\text{vehicle impact}}$ [km/h]</td>
<td>20</td>
</tr>
<tr>
<td>$V_{\text{pedestrian}}$ [m/s]</td>
<td>1.5</td>
</tr>
<tr>
<td>$R_{\text{vehicle}}$ [m]</td>
<td>6</td>
</tr>
<tr>
<td>$D_{\text{pedestrian}}$ [$^\circ$]</td>
<td>+90°</td>
</tr>
<tr>
<td>$X_{\text{vehicle-pedestrian}}$ [m]</td>
<td>30</td>
</tr>
<tr>
<td>$Y_{\text{vehicle-pedestrian}}$ [m]</td>
<td>6 + 2</td>
</tr>
<tr>
<td>$T_{\text{vehicle}}$ [s]$^{1)}$</td>
<td>pc</td>
</tr>
<tr>
<td>$H_{\text{pedestrian}}$ [m]</td>
<td>170</td>
</tr>
</tbody>
</table>

1) pc = passenger car.

From the accident data it was concluded that a significant amount of the accidents occur during daytime with dry weather. Therefore, it was decided that all tests will be performed under normal daylight, with dry weather and at a dry road. In all tests the impact point is mid-vehicle at the vehicle front.
4.1.4 Test objects & test set-up

In general, the objects used in the pre-crash performance tests have to represent a pedestrian for the sensor system. Although the requirements for a pre-crash test object for pedestrian detection are dependent on the sensor technology used and the type of test that is performed, some generic specifications can be given:

- the object should have a realistic sensor profile representing a pedestrian of a certain standing height within the complete sensor field of view. As the relative approaching angle between vehicle and pedestrian is changing with the distance between the vehicle and the pedestrian, the sensor profile should be representative for different approaching angles;
- the object should be able to approach the vehicle under test (VUT) according to the defined test conditions (especially with respect to the defined relative positions and motions) until the time-to-collision is significantly lower than the minimal required actuator fire trigger time;
- the defined motions and the location of the impact point on the vehicle should be repeatable and accurate;
- as a series of tests will be done, the VUT should not be significantly damaged during the testing (no more than slight scratches);
- the test object should be robust.

For a specific sensor or combination of sensors, these generic specifications could lead to different requirements for the object. For an infrared sensor for instance, the temperature profile of the object is relevant, whereas the performance of a video or radar sensor is independent from the temperature profile of the object. For the system evaluated in APROSYS WP1.3, making use of a short range radar sensor cluster, the main requirements are considered to be:

- a radar profile representing a pedestrian within the complete sensor field of view. As the relative approaching angle is changing with the distance between the pedestrian and the vehicle, the radar profile should be representative for different approaching angles. The standing height of the pedestrian represented by the object is about 1.7 m, which is considered to be the average from the accident statistics;
- the object should be able to approach the VUT according to the defined test conditions until the time-to-collision is significantly lower than 60 ms;
- the VUT should not be significantly damaged during the testing (no more than slight scratches). This is especially true since the VUT is a specially prepared vehicle.
- in all cases the impact point is front mid-vehicle. The position of the impact point on the vehicle should be reproducible and accurate.

Several test objects for pedestrian pre-crash testing have been developed already in earlier studies. Table 7 provides an overview of the objects available from various WP1.3 partners and from the PREVENT subproject APALACI / COMPOSE [5].
<table>
<thead>
<tr>
<th>Type</th>
<th>Impact</th>
<th>Suitable sensors types</th>
<th>Weight [kg]</th>
<th>Dimensions</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam pole with alu foil inside (Siemens / PReVENT)</td>
<td>Yes (relative low velocity)</td>
<td>Laser, Radar</td>
<td>Low mass</td>
<td>Variable</td>
<td></td>
</tr>
</tbody>
</table>
| Foam pedestrian with alu foil inside (VW) | Yes (relative low velocity) | Laser, Radar, Video | Low mass | Standing height: 1.85 m with 'baseplate'  
Shoulder width: 0.6 m  
Thickness: 0.3 m |
| Inflatable pedestrian (VW) | Yes, up to 30 km/h | Infrared, Laser, Radar, Video | 13 | Standing height: 1.5 – 1.9 m |
| Pedestrian with wireframe skeleton (TRL) | No (tested up to 25 km/h impact velocity) | Infrared, Laser, Radar, Video | n/a | n/a |
All objects shown in Table 7 are stationary objects. However, as can be seen in the results from the accident study, a pedestrian is often moving during a vehicle-pedestrian accident. Therefore, a moving test object representing a moving pedestrian is considered more realistic than a stationary object. In Appendix B, an example of a test set-up with a moving object is provided.

As can be seen in Figure 2, the experimental vehicle is equipped with a so-called cowcatcher. This enables testing with a very low time-to-collision without significant damage to the vehicle front when using compliant objects. However, the object should have a height of at least 80 cm (to avoid contact with the cooling unit) and should not exceed 130 cm due to a possible “destructive” contact with the bonnet. Finally the weight and mass distribution within the object are relevant for a proper working of the cowcatcher.

4.2 Crash performance tests

4.2.1 Test scenarios

The crash performance tests will be performed as much as possible in accordance with the EU Directive 2003/102/EC phase 1 [6]. As the focus in the evaluation work performed within APROSYS WP1.3 is more on the pre-crash performance, no full testing program for the crash performance will be executed. Instead a limited amount of tests are performed on the bonnet and on the vehicle front structure for demonstration purposes. The tests on the vehicle front structure do include both the switchable bumper stiffness and the moveable lower bumper.

The tests on the bonnet are performed with a 3.5 kg head form impactor as described in the EC Directive. The impact velocity of the head form is 35 km/h. During the impact, the acceleration of the head form is measured and the head performance criterion (HPC which is similar to HIC) value is calculated.

The tests on the vehicle front structure are performed with the leg form as described in the EC Directive. The impact velocity of the leg form is 40 km/h. During the impact the following signals are measured:
- knee bending angle;
- knee shear displacement;
- lower leg acceleration.

Note that the tests are performed with fully deployed protective devices. Actuator fire trigger signals are simulated to get correct activation times for the switchable bumper, the moveable lower bumper and the pop-up bonnet.
4.2.2 Assessment criteria
The measured values are compared with the limits provided in the EC Directive. For the leg form to bumper test:
- the maximum dynamic knee bending angle shall not exceed 21.0°;
- the maximum dynamic knee shearing displacement shall not exceed 6.0 mm;
- the acceleration measured at the upper end of the tibia shall not exceed 200 g.

For the child/small adult head form to bonnet top tests the HPC shall not exceed 1000 over 2/3 of the bonnet test area and 2000 for the remaining 1/3 of the bonnet test area.

4.2.3 Test set-up definition
The test set-up can be seen in Figure 7. In total 4 leg form impactor tests are performed at two different test facilities (at SRS and TRL). The impact points on the bumper are:
- mid vehicle;
- at the lower longitudinal beam.

In addition 6 head form to bonnet impactor tests are performed at two different test facilities (SRS and TRL). Tests are performed at three different locations on the bonnet:
- middle region;
- hinge region;
- in between the middle and the hinge region.

![Figure 7: Schematic test set-up for the pedestrian subsystem impact tests](image)

4.3 Driver-in-the-loop performance tests

Driver-in-the-loop tests can be used to:
- investigate possible reactions of drivers affecting the performance of the system. This could be important in case of semi-autonomous safety systems like brake assist;
- identify (negative) side effects caused by the drivers reaction upon the activation of the system.

For the pre-crash pedestrian protection system, the activation of the pop-up bonnet has a potential to distract the driver, because of the reduction of the field of view of the driver and the noise generated by the activation of the bonnet. This could result in a negative side effect, especially in case of a false alarms. Therefore a series of driver-in-the-loop tests are performed to
evaluate the driver reaction in case of a bonnet popping-up. This is done using driving simulator tests with a moving base driving simulator.

The other protective devices are not in the field of view of the driver and therefore are thought to have no significant potential to distract the driver. These devices are not evaluated using by driver-in-the-loop tests.

4.3.1 Test scenarios

In total three different scenarios are evaluated:

- a ‘true’ pedestrian accident scenario. A driver drives in the city centre and is confronted with a suddenly crossing pedestrian. The pop-up bonnet is activated;
- a ‘false alarm’ scenario. The driver is driving on the highway with high speed and is performing an overtaking manoeuvre. During this overtaking manoeuvre, the pop-up bonnet is activated. This scenario was taken to evaluate the effect of false alarms that could happen in reality. Although this is no problem for the system as the system is reversible, the reaction of the driver upon the activation of the system could cause a potential risk;
- a ‘cognitive disorder’ scenario. In this scenario the driver drives on the highway at high speed and a stone smash against the windscreen is simulated. This is a reference scenario. The driver reactions of the other two scenarios can be compared with the driver reactions in this scenario.

In all three scenarios, the following is recorded:

- driver reaction related to the traffic scenario by video (face, feet and whole body reaction);
- driver’s subjective perception (emotion) by an interview. Before and after the test an extensive interview is done, during the test a brief interview is done after each event;
- vehicle data (speed, vehicle dynamics);
- control elements (steering wheel angle, brake pedal position, accelerator pedal position).

The results are analysed to show the most common driver reactions and the range of driver reactions due to activation of the pop-up bonnet. As such the study does provide insight in the side effect that can be expected by the introduction of a deployable bonnet system.

4.3.2 Assessment criteria

Currently there are no generally agreed objective criteria are available. However, a relative comparison can be made by comparing the results from the ‘true’ scenario and the ‘false alarm’ scenario with the ‘cognitive disorder’ scenario. Via this comparison the risk that the driver causes a dangerous situation due to the activation of the pop-up bonnet can be obtained. Especially in the ‘false alarm’ scenario, this risk should not be significantly higher than the risk in the ‘cognitive disorder’ scenario.

4.4 Relevant supporting information

In the evaluation method the system supplier could bring in relevant supporting information via Box 7. Relevant supporting information is thought to be information providing more insight in the performance of the sensing system in other (real world) conditions than the conditions evaluated in the tests performed in Box 6.

To provide more insight in the performance of the sensing system in situations not included in the pre-crash performance tests, a simulation study in PreScan is performed [7]. PreScan is a numerical simulation environment for the design and evaluation of the next generation of vehicles with sensors to make road traffic safer. Within PreScan a vehicle can actually sense its surroundings and – based on the decision algorithms implemented – react to it. Typical detection
systems that can be used range from radar, lidar and stereo vision, to car-2-car and car-2-infrastructure communication systems.

In the study, a number of different scenarios will be simulated. The scenarios will be based on the selected accident scenarios as specified in section 3.4. However, focus is on:

- variation of the most important scenario parameters to show the sensor system performance beyond the specific conditions tested in the pre-crash performance tests;
- simulation of scenarios using information that can not directly be derived from the accident analysis, but is thought to be relevant for pedestrian accidents. As such for instance involvement of other objects (obstruction of view scenarios and multi target capability) will be evaluated.

In total 60 simulations are performed, including 6 of the test conditions as defined in section 4.1.3. The actuator fire trigger times resulting from these 6 simulations are compared with the actuator fire trigger times from the pre-crash performance experiments, indicating the validity of the PreScan simulations.

Based on the available information about the 24 GHz short range radar sensors implemented in the experimental vehicle, the sensors will be modelled in PreScan and virtually be mounted at the proper locations at a vehicle model. The radar sensor model is a simplified model and therefore do not include all radar specific features. The used sensor model is configurated as much as possible to the radar sensors used in the experimental vehicle. Table 8 indicates the parameters from the sensor model that can be configured.

**Table 8: The configured radar model parameters and the desired values [8]**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Desired value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>from 0.15 m to 20 m</td>
</tr>
<tr>
<td>Range accuracy</td>
<td>0.02 m</td>
</tr>
<tr>
<td>Object resolution</td>
<td>0.15 m</td>
</tr>
<tr>
<td>Horizontal opening angle</td>
<td>40 °</td>
</tr>
<tr>
<td>Angular accuracy</td>
<td>to be defined based on [8]</td>
</tr>
<tr>
<td>Cycle time</td>
<td>40 ms</td>
</tr>
<tr>
<td>Max. number of tracked objects</td>
<td>10</td>
</tr>
</tbody>
</table>

Parameter values shown in Table 8 are chosen from the specifications of the short range radar sensors used in the experimental vehicle. More detailed information of these sensors can be found in [8] and [9].

The sensor models will provide object related information to the actuator fire decision algorithm. This algorithm is equal to the algorithm implemented in the experimental vehicle and is linked to PreScan via Matlab. From the decision algorithm, the actuator fire trigger time is measured w.r.t. the start of the collision which is defined as time zero. The resulting trigger times, expressed in time-to-collision, are be compared with the assessment criteria as defined for the evaluation of the pre-crash performance (section 4.1.2).
5 Discussion

The pre-crash pedestrian protection system is used as an example application. The main aim of this work is to evaluate and update the generic evaluation methodology. It is clearly not the objective to assess the performance of the system under test, also because this system is still in an experimental stage. Although the generic evaluation method covers the complete performance of protective systems, the focus is on pre-crash performance and on driver-in-the-loop performance as these are relatively new aspects in the methodology.

Despite the non-destructive nature of the pre-crash performance tests the number of test conditions is still relatively limited. Although the intention of the WP1.3 methodology is to accurately take into account the real world relevance of each test condition, this might not be possible with a limited number of test conditions. In that case it can be considered to calculate the correct relevance by additional (mathematical) weighting of the test conditions per scenario.

Originally it was intended to evaluate an experimental vehicle from the COMPOSE project [3]. This experimental vehicle was equipped with a radar network and a FIR camera for detecting pedestrians. Unfortunately this vehicle was not anymore available for evaluation within APROSYS WP1.3. As alternative, an experimental vehicle from Daimler Chrysler was selected with a short range radar sensing system originally developed to detect cars. For the pedestrian detection application, the detection algorithm was modified such that the sensing system can detect pedestrians. However, it should be noted that with the use of a short range radar sensor cluster only a limited performance is expected.

In Table 7 various test objects are shown that are used to evaluate the pedestrian detection capabilities of pre-crash pedestrian protection systems. Unfortunately only little information was found on how well the different object did represent a pedestrian for a (short range) radar sensor system. In the APRVRU project a comparison was made between pedestrians and the ‘pedestrian with wire-frame skeleton’ object. However, only the range was reported and no information was given on the for instance the radar cross section or the signal-noise-ratio of the object. In addition, also tests with various sensors and pedestrians were also performed within the SAVE-U project [10]. For the short range radar sensor it was concluded in SAVE-U that:

- metallic parts of vehicles do much better reflect than human tissue (at least an order of magnitude difference);
- pedestrians are well detectable with a 24 GHz short range radar;
- the fluctuation in signal amplitude caused by the dynamic pedestrian and environment is much more than the difference in signal amplitude caused by different clothing;
- due to a high fluctuation in signal amplitude, it is difficult to distinguish pedestrians from other objects such as cars and trees.

Here is should be noted that the SAVE-U project ended in 2005, whereas radar technology for automotive applications is progressing rapidly.

For the evaluation of the pre-crash pedestrian protection system in APROSYS WP1.3 it was decided to use a dedicated object, representing a pedestrian. A limited set of preliminary tests is performed with a 24 GHz short range radar sensor, pedestrians and available objects of different sizes to compare the radar profiles. Based on the results a representative pre-crash object is selected and used for the APROSYS WP1.3 pre-crash performance tests. These tests and the resulting characteristics of the test objects are reported separately.

As can be seen in section 4.1.2, the time needed for full activation of the actuator has been assumed at this stage. In a later stage, the activation time of the three different actuators will be measured. The measured actuator times will be compared with the assumed the actuator times and if necessary the assumed actuator activation times and the corresponding required actuator fire trigger times will be corrected.

The PreScan study performed indicates the performance of the sensing system in a number of conditions not tested experimentally. Here it should be noted, although possibilities for numerical
simulation of the exterior sensing is expanding rapidly, several simplifications have been made. For instance the sensor model used is somewhat simplified. Therefore this study should be seen as an example and it will indicate the possibilities and limitations of this type of simulation studies.

As mentioned in [1] the criteria to evaluate the pre-crash performance are used to objectively judge if a test is passed / failed. In the application currently under evaluation, the safety system consists of three different actuators each requiring its own pass / fail criteria:

- in case the actuator fire trigger is provided earlier then or equal to 160 ms time-to-collision (TTC ≥ 160 ms), all protective devices could be activated in time and the test is passed.
- if the trigger is provided between 160 and 60 ms time-to-collision, the test is passed only for the protective devices that could be activated in time.
- if the trigger is provided later then 60 ms time-to-collision (TTC < 60 ms) none of the protective devices could be activates in time and the test is not passed.

How the outcome of the pre-crash performance tests will be used to come to an overall system performance (Box 8 of the methodology) is open for discussion. A proper way to combine the performance ratings from the pre-crash performance, the crash performance and the relevant supporting information still has to be developed. In addition, this is very much dependent on the interest of the organisation applying such a methodology. Therefore, it was decided not to calculate this overall system performance from the evaluation done within APROSYS WP1.3. It is considered not critical for the evaluation of the methodology.

It should be noted that the work performed in APROSYS WP1.3 is also linked to the work performed by APSN. Objective 1 of APSN defines the activities around sharing of facilities. Within this Objective, a sub-objective “Pilot Case Specification” has been specified to show the feasibility of sharing experimental and / or virtual facilities / tools by means of a specific application example. As in APROSYS WP1.3 several partners are preforming parts of the tests, sharing of facilities is examplied within APROSYS WP1.3. Therefore, a link is established between APSN and APROSYS as a “partner project”. The main objective of the pilot case is to verify the general applicability of the evaluation methodology. Furthermore, with respect to the pedestrian-protection safety system, the pilot case aims at a detailed requirement analysis for the specific test-objects (i.e. pedestrian models) needed for pre-crash performance tests. A more detailed description of the APSN activities can be found in Appendix D.

Within this report, the minimum required actuator fire trigger times have been calculated based on estimated activation times. The actual activation times for the different actuators will be measured in the crash performance tests. Based on the measured times updated minimum required fire trigger times will be calculated if necessary.
6 Conclusions & Recommendations

In this document a system specific test plan has been developed from the generic evaluation methodology from APROSYS WP1.3:

- based on the pre-crash pedestrian protection system and the accident data, pre-crash performance tests have been specified. In total three different generic scenarios were specified. In addition 13 test conditions have been defined related to these three scenarios. The number of test conditions related to each scenario does reflect the real world relevance of each scenario in terms of occurrence of accidents with MAIS 2+ injuries;
- head form and leg form tests have been defined to evaluate the crash performance of the actuator systems consisting of a pop-up bonnet, a switchable bumper stiffness and a moveable lower bumper. These tests are performed according to the test method described by Directive 2003/102/EC;
- driver-in-the-loop tests in a moving base driving simulator were specified. These tests do evaluate the driver reaction upon a popping-up bonnet in both (near) accident and false alarm situations. As such they provide insight in the risk that a driver causes a dangerous situation due to the activation of the bonnet;
- relevant supporting information is provided via numerical simulations of the environmental sensor system. The sensor and decision algorithm modelled and numerically applied in a number of different crash situations. These simulations indicate the pre-crash performance of the pre-crash pedestrian protection system in conditions additional to the conditions used for the pre-crash performance tests.

Note that the tests performed in APROSYS Task 1.3.3 are performed to review and further develop the generic evaluation methodology for advanced safety systems developed in Task 1.3.2. In Task 1.3.4 the test results and the experiences will be used to update the evaluation methodology. In addition APROSYS WP6.5 will provide results from the testing with the pre-crash side protection system.
7 References


Appendix A  Accident analysis

Pedestrian accident scenarios: Overview
A summary of equivalent accident scenarios from the GIDAS database can be found in Figure A - 1. These scenarios have been developed from 1924 accidents between pedestrians and passenger cars or MPV’s.
Figure A - 1: Summary of accident scenarios from GIDAS database

Pedestrian accident scenarios: Object and environmental parameters

From the 1924 pedestrian accidents, the frontal accidents were selected with an injury severity of MAIS2+. The resulting 649 frontal pedestrian accidents have been further analysed to obtain more detailed information on object and environmental parameters. The results can be found in Figure A - 2 to Figure A - 13.
Figure A - 2: Initial velocity of colliding vehicle

Figure A - 3: Impact velocity of colliding vehicle
European funded project
TIP3-CT-2004-506503

Figure A - 4: Pedestrian velocity

Figure A - 5: The pedestrian moving direction for scenario 1 (left), scenario 2 (centre) and scenario 3 (right). From the 649 accidents, 43 did not fit into one of these categories.
Figure A - 6: Pedestrian impact position at vehicle

Figure A - 7: Driver reaction: braking (left) and steering (right)
Figure A - 8: Accident environment

Figure A - 9: Road layout
Figure A - 12: Time of day

Figure A - 13: Precipitation
Appendix B  Overview of PreCrash and driver-in-the-loop test facilities

Below you find a brief description of the test facilities of Daimler Chrysler, Siemens Restraint Systems, TRL and TNO.

**Daimler Chrysler**
Daimler Chrysler has the a moving base driving simulator (see Figure B - 1) able to realistically simulate all movements of a vehicle in various driving situations.

![Figure B - 1: The moving base driving simulator](image)

**Siemens Restaunt Systems**
Siemens Restraint Systems has following test capabilities suitable for pre-crash testing:
- Full scale crash runway of 160 m long
- Crash hall of 25 x 40 m
- Outdoor side of 45 m long (proving ground)

Vehicle velocity control can be done via the hydraulic crash propulsion system, a cable and a trolley and guiding rails. A wide range of predefined vehicle steering actions can be performed using a hydraulic control system. Both steer angle and timing can be defined.

The proposed test principle for a pedestrian object moving device can be seen in Figure B - 2.
The light weight test object will be accelerated with a winch and is moving on a ropeway. The object is connected to the ropeway via a Velcro strap, which splits the connection early in the contact phase.

**Transport Research Laboratories**

TRL has following capabilities for pre-crash testing:

- Research track, including a large unobstructed central test area (c300m diameter), three lane straight (550m), a 2km loop and banked bend.
- Private road network (2.5km) with roadside furniture and road markings representative of an urban environment

These facilities can be used in conjunction with TRL’s qualified test drivers to conduct appropriate test scenarios and sensor assessments.

**TRL has the following crash facilites:**

- Impact Sled Facility (ISF)
- Impact Test Facility (ITF)

In addition, TRL also has pedestrian test facilities (for EC Directive and EuroNCAP testing).

**TNO**

TNO has the following pre-crash test capabilities

- VeHIL (Indoor test facility of 40 m wide and 200 m long with robot vehilces and a roller bench)
- Full scale crash track of 160 m long

Within the VeHIL facility the vehicle under test (VUT) is put stationary on a roller bench. With the use of Moving Bases (MB) realistic traffic scenarios can be experimentally simulated in a highly controlled environment. The Moving Bases are able to make complex movements such that they can approach the VUT to about 500 ms time-to-collision without collision.

Within the full scale crash facility the VUT is positioned stationary and the approaching object is coupled to the test track. Just before the collision the object is decelerated with the use of crush tubes. In this way the object can approach the VUT to less than 100 ms time-to-collision without any consequent collision with the VUT. Currently only linear scenarios can be performed, however non-destructive test methods for testing non-linear scenarios with very low time-to-collision are currently being investigated.
Appendix C  Determination of required bonnet activation time

To evaluate the required time the bonnet has to be popped-up in car-to-pedestrian impact, a number of multibody simulations have been performed with the MADYMO human pedestrian models and a model of the Chrysler neon frontend. An overview of the simulations performed can be seen in Table C - 1.

Table C - 1: Overview of the simulations and resulting contact times

<table>
<thead>
<tr>
<th>#</th>
<th>MADYMO pedestrian dummy type</th>
<th>Collision-Speed</th>
<th>Pedestrian Orientation</th>
<th>Time of first body contact [ms]</th>
<th>Time of first head contact [ms]</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6yd Child</td>
<td>40</td>
<td>90</td>
<td>30</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6yd Child</td>
<td>40</td>
<td>180</td>
<td></td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6yd Child bike</td>
<td>40</td>
<td>90</td>
<td>20</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5% Woman</td>
<td>40</td>
<td>90</td>
<td>50</td>
<td>75</td>
<td>elbow contact</td>
</tr>
<tr>
<td>5</td>
<td>50% Man</td>
<td>20</td>
<td>90</td>
<td>65</td>
<td>195</td>
<td>elbow contact</td>
</tr>
<tr>
<td>6</td>
<td>50% Man</td>
<td>30</td>
<td>90</td>
<td>65</td>
<td>235</td>
<td>elbow contact</td>
</tr>
<tr>
<td>7</td>
<td>50% Man</td>
<td>40</td>
<td>90</td>
<td>55</td>
<td>240</td>
<td>elbow contact</td>
</tr>
<tr>
<td>8</td>
<td>95% Man</td>
<td>40</td>
<td>90</td>
<td>45</td>
<td>135</td>
<td>elbow contact</td>
</tr>
</tbody>
</table>

Figures C - 1 till Figure C - 8 show the initial set-up and the kinematics at the time of head contact and the time of contact with the upper body (thorax) can be seen for the different simulations.

Figure C - 1: Simulation #1: 6 year old child at 90°; collision speed is 40 km/h
Figure C - 2: Simulation #2: 6 year old child at 180°; collision speed is 40 km/h

Figure C - 3: Simulation #3: 6 year old child on bike at 90°; collision speed is 40 km/h

Figure C - 4: Simulation #3: 5th percentile female at 90°; collision speed is 40 km/h

Figure C - 5: Simulation #5: average male at 90°; collision speed is 20 km/h
Figure C - 6: Simulation #6: average male at 90°; collision speed is 30 km/h

Figure C - 7: Simulation #7: average male at 90°; collision speed is 40 km/h
Figure C-8: Simulation #8: large male at 90°; collision speed is 40 km/h
Appendix D  APSN Pilot case specification

Date: 25th April 2007

Objective 1: Sharing of facilities

Pilot case specification (sub objective 1.2)

Objective:

The overall objective of the pilot case is to show the feasibility of sharing experimental and/or virtual facilities/tools by means of a concrete application example. To this, a link is established to the IP APROSYS as a “partner project”. In APROSYS WP1.3 a draft generic “Evaluation methodology for Advanced Safety Systems” was developed recently (see Appendix). To test the applicability of the methodology it is applied to a pre-crash pedestrian-protection system.

The main objective of the pilot case is to verify the general applicability of the evaluation methodology developed in APROSYS for the assessment of various (advanced) safety systems. Furthermore, with regard to the pedestrian-protection safety system, the pilot case aims at a requirements analysis of the specific test-objects (i.e. pedestrian models) needed for performance tests. The pilot case partners share their particular analysis and test facilities to provide complementary specifications and design recommendations for suited test-objects.

Approach:

The pilot case is set-up as a “Virtual Evaluation Laboratory” (EvalLab), which is considered as a (virtual) service institution hosting various facilities to provide evaluation, test and consultancy services in the field of Integrative Safety. The EvalLab pilot case focuses on the category of safety systems as they are in the scope of APROSYS WP1.3 (“Advanced Safety Functions”). According to the approach in the APROSYS Task 1.3.1 (“Evaluation methodology for Advanced Safety Systems”) a pedestrian-protection system will be taken as a reference safety system to verify the evaluation methodology.

The pedestrian-protection system taken into consideration in principal effects a foresighted, sensor-based release of protection measures at the vehicle including adjustable bumper stiffness and extensible resp. deployable lower bumper and hood components. Because a “complete system” resp. a vehicle which includes all system components of the pedestrian-protection target system is not available, the evaluation tests will be executed by means of various generic system components. The evaluation method developed in APROSYS WP1.3 explicitly allows for this approach. According to this method, the APROSYS tests are planned to be executed in various “clusters”:

- Pre-crash performance tests (sensor tests) will be performed at TNO (stationary sensor vehicle + robot vehicle resp. accordingly moving pedestrian dummy), at Siemens SRS (moving resp. controlled sensor vehicle) and at TRL (sensor vehicle with robot control),
- Crash performance tests (actuator tests) will be performed at Siemens SRS and probably at TRL with the actuator components described above,
- Driver-in-the-loop tests will be performed at the DaimlerChrysler driving simulator in Berlin (moving-based simulator) with emphasis on the investigation of drivers’ reactions on (necessary and unnecessary) deployment events at the hood. (The tests at DaimlerChrysler have already been conducted in Febr. 2007).

The pilot case specification is set-up in coordination with the targets of the APROSYS WP1.3 “partner” project: To verify the usability of the generic APROSYS evaluation methodology, its
applicability to other (advanced) safety systems is analysed systematically in the pilot case. Specific conditions which have to be considered in using the methodology are specified and a set of use recommendations will be compiled.

The requirements analysis with regard to specific test-objects for performance tests with the pedestrian-protection safety system will start with the test specifications set-up in APROSYS WP1.3 (Task 1.3.3). From this, it will be analysed which new requirements have to be considered in comparison to the use of existing test-objects. Based on the analysis, suited specifications will be defined and design recommendations will be provided. Wherever applicable, prototypical solutions will be implemented.

**Pilot case partners & contributions:**

The pilot case partners will share facilities/tools to provide the following contributions:

- **Fraunhofer IVI** will coordinate the pilot case and the link to the APROSYS WP1.3 “partner project”. It will conduct a comparative usability analysis of the generic APROSYS evaluation methodology. Furthermore, simulator tests will be carried out at the Fraunhofer IVI fixed-based driving simulator in Dresden with emphasis on the investigation of the impact of the appearance of (simulated) test-objects in driver-in-the-loop tests.

- **DaimlerChrysler** will utilize the driver-in-the-loop tests at its moving-based driving simulator in Dresden with emphasis on the investigation of the impact of the development tool will be applied.

- **TNO** will analyse specific requirements on test-objects for pre-crash performance tests. In cooperation with FTSS it will define suited test-object specifications. The specifications will then be applied in the pre-crash performance tests (sensor tests) at the TNO test facility in Helmond which will be conducted in the context of the APROSYS project.

- **FTSS** will, in close cooperation with TRL, identify implications of the existing legform impactor for usage in crash performance evaluation. These implications deal with the sensitivity to the impact range, which is changing under pre-crash performance. Together with TRL and TUG, FTSS will define a set of (draft) specifications and provide design recommendations for legform impactors.

- **TUG** will analyze pedestrian accident scenarios against the performance of pre-crash sensor systems (sensor range, time for recognition, brake level activation) and come back with the effect to the accident (reduction of impact speed, different impact location, avoidance of impact). One real world PC-pedestrian case will be used as a basis for the analysis (e.g. pedestrian crossing). The TUG analyses will be linked to the accident scenarios, which are developed in APROSYS WP1.3.