# PROTECTOR

***PREVENTIVE SAFETY FOR UN-PROTECTED ROAD USER***

Information Society Technologies: Systems and Services for the Citizen

## Project IST – 1999 - 10107

Deliverable No. D06.5
version 2.0

# Final Report


Authors: Renzo Cicilloni

(contributions from partners)



Dissemination Level: PUB

Deliverable Type: R

Contract Date: 24/11/1999

Document Date: 10/2003



Partners

CRF(it), DaimlerChryler (de), MAN (de), IBEO (de), Siemens (de)

TÜV (de), CSST(it), Univ. Pavia (it), IKA(de)



Commission of the European Communities – Directorate-General Information Society

# *Credits*

This document was prepared by partners of the *PROTECTOR* consortium. Please contact one of the following project partners for further informations regarding this document or the project.

- Centro Ricerche Fiat S.C.p.A.
- DaimlerChrysler AG
- MAN Nutzfahrzeuge AG
- IBEO Lasertechnik Hipp KG
- SIEMENS VDO
- TÜV Kraftfahrt GmbH
- Università di Pavia
- Institut fuer Kraftfahrwesen Aachen
- Centro Studi sui Sistemi di Trasporto

Workpackage Leader:

| | |
|---|---|
| Name: | Renzo Cicilloni |
| Company: | Centro Ricerche Fiat |
| Phone: | +39 0119083012 |
| Fax: | +39 0119083672 |
| E-mail: | renzo.cicilloni@crf.it |

Project Co-ordinator:

| | |
|---|---|
| Name: | Renzo Cicilloni |
| Company: | Centro Ricerche Fiat |
| Phone: | +39 0119083012 |
| Fax: | +39 0119083672 |
| E-mail: | renzo.cicilloni@crf.it |

# *Revision chart and history log*

| Version | Date | Reason |
|---|---|---|
| 0.1 | 07/03/2003 | Draft to the partners |
| 0.2 | 11/03/2003 | Second draft to the partners<br>Revisited and add more results |
| 2.0 | | |
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# Table of contents

# 1. Project objectives and approach

Advanced Driver Assistance Systems (ADAS) are in-vehicle systems for preventive safety with the intent to advise, warn and support the driver in his/her interactions with the vehicle and the surrounding traffic. They are designed to provide assistance in controlling the vehicle, to improve its behaviour in the traffic and to avoid accidents. To date the topic of developing an preventive safety system with the aim of preventing accidents among vehicles and unprotected road users has not been tackled yet. The main reason is because the applied technologies, principally developed to detect other vehicles, have limitations which exclude the possibility, or make it difficult, to detect Vulnerable Road Users (VRU: pedestrian, cyclist, motorcyclist). At the same time the use of active or passive safety systems on vehicle is not able to avoid this type of road accidents.

This category of users is now considered in PROTECTOR, a project with the objective of developing a warning system for VRU protection.

For such objective, three main points require specific developments: the sensorial system, the warning strategies and the human machine interface able to support both the driver and the VRU. Therefore PROTECTOR has included a significant attention on how to support, validate and guide these developments, by a common definition of system requirements, by test-site operation and by using common guidelines at European level for system evaluation and validation. Other important points of the project have been the definition of the application in terms of functionality, architecture, development and validation of different implementation concepts, these considering user needs, scenarios to be covered, limitations and misuses, interactions among the different on-board and off-board systems. The investigation of the road user needs is relevant both in the definition phase of the PROTECTOR requirements and in the final demonstration phase.

The functional verification and the test for user acceptance have been performed in part in a test track reproducing the critical scenarios, and for the most part in real word conditions in order to evaluate the effectiveness of the PROTECTOR system.

With all these activities, PROTECTOR continues in the research and development of ADAS on the way to “zero accident” vehicles, by solving some functional and technological limits of several of the existing applications to improve safety for road users. In fact, by the combination of the technical developments obtained in this project and of other results from EC research, including horizontal support activities, it is possible to extend the ADAS support to all road users.

## 1.1 Summary of main achievements

The main achievements can be summarised as follows:

- **Identification of five scenarios more representative of the road accidents**
  It has been obtained from accident analysis and user need investigation.
- **Functional specification for an integrative approach**
  The PROTECTOR project, starting from the above-described activity, defined the system specification. The specification has been matched with the user needs analysis.
  - **Common System Architecture**
    A common approach for a complete architectural decomposition has been used, considering the complexity of the system at vehicle and surrounding environment level.
  - **Benchmarking for PROTECTOR communication system**
    The investigation on the communication system highlighted that no suitable system is on the market, however it seems that the Bluetooth technology could be a candidate to fulfil the requirements of the application in the next future.
  - **False alarm reduction**
    The Risk Assessment Module, developed to evaluate the accident risk probability, have been successfully tested.
  - **HMI Specification Guidelines**
    For a correct development of the PROTECTOR function, different possible solutions for human-machine interface have been investigated, also in cooperation with other EU projects.
- **Development of sensorial systems (radar, laser scanner, stereo-video system) able to detect/classify VRU**
  these sensors have been specifically developed and installed in three demonstrator vehicles; they have been tested on a test track and in real urban environment.
- **Results from the system test and user trials in test track and real environment**
  One fully equipped test site and special targets have been developed in order to have reproduceable target characteristic for the different sensorial systems. The evaluation of all demonstrators has been made, considering both the demonstrator performance and effectiveness (objective level) and the User's point of view (subjective level).

- **Comparison between simulation and road tests data**
  All data logged during the test were used for the statistical identification of the system performances.

The PROTECTOR project has shown the technical feasibility and the benefits of VRU detection and classification, risk assessment and warning strategies, but also some existing limitations at present for such a system.

## *1.2 Description of work*

To achieve the projects goals PROTECTOR adopts the recommended phases of the RTD&D projects.

The project starts with the **definition of the PROTECTOR concept** (in terms of application) in order to achieve its objectives. The work is carried out taking in consideration the analysis of the accident through collection of European data and the user needs analysis. The collection and analysis was made of accident data from Italy, Germany, French, Sweden, and USA and the investigation of user need was made trough multimedia questionnaire. The results were used to define the relevant system scenarios (more critics) and to identify the specification, including the technical requirements, of the application. The work has explicitly designed the environment (border) of the system and fixed the impact of the system on vehicles, drivers and vulnerable road users. Based upon the previous activities the project designed the PROTECTOR system: technologies identification, procurement and adaptation.

The activities related to the **HMI** definition and the **Warning and Control Strategies** development have been mainly supported by the simulation study.

The **sensing system analysis** contributes to the identification of the sensors to be adapted for the application (closer to the system operational requirements), and the communication system analysis has been focused to the identification of an existing on the market component (transponders, microwave/optical reflectors, others) and to the definition of a minimal set of modification at interface level.

Relevant are the outputs of the activities worked out in the “System on Vehicle Architecture Design” and “Sub-system components analysis and adaptation” sub-work packages to proceed with the project. The following step is the **building of the demonstrators** and their **validation**. A first phase of the work is dedicated to evaluate on the demonstrator which of the three sensorial technologies are respecting the technical requirements.

Both **commercial vehicle and automobiles were tested** in the dedicated test site developed in a parallel phase. Finally the functional test certified the

possibility to start the validation phase through the verification of the systems functionality. The following step comprises the planning and execution of the necessary test to evaluate PROTECTOR: the performances of the demonstrators vehicles were validated with final users. A parallel evaluation was done at simulation level to guarantee the statistical analysis of the system benefits.

The validation of the system and the concept modelling evaluation give the input to the **Cost/Benefits analysis** of the PROTECTOR implementation.

The last phase concerns the **exploitation** of the results. The project phases in PROTECTOR are mapped onto four technical work packages (WP2 - WP5), which are supported by two organisational work packages covering the Operational Project Management and the Dissemination & Implementation phases.

The Consortium includes vehicles manufacturers from around Europe, who have a variety of experiences in safety systems, automotive suppliers for the sensor development and research/university organisations for the simulation phase and for the analysis of the system functionality.

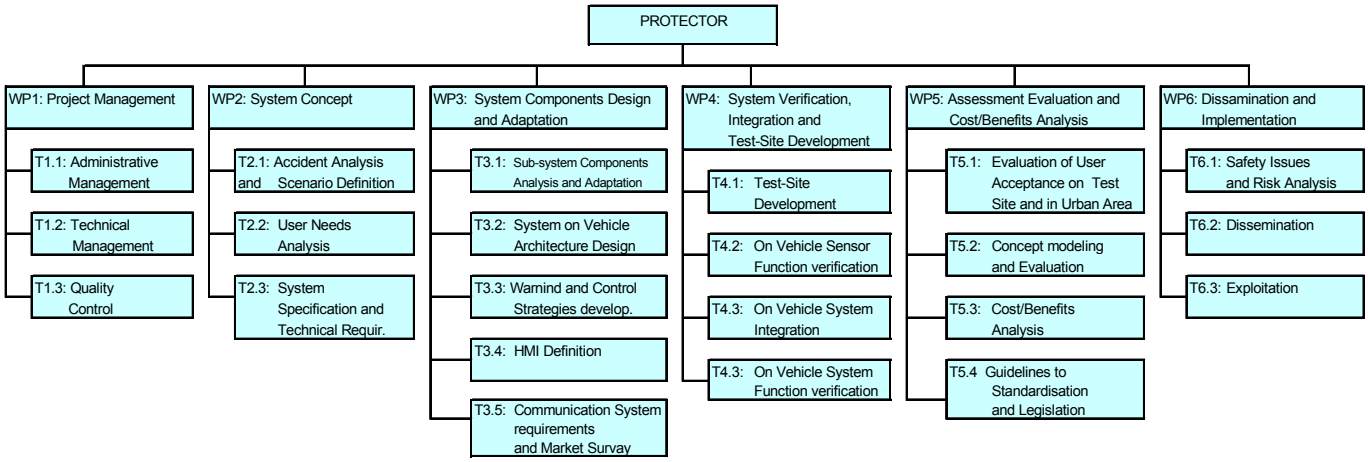



Figure 1: Work-packages & Sub-workpackages of the Project

## *1.3 Approach followed to achieve project objectives*

PROTECTOR involved from the beginning a group of potential users in order to define their needs. This process is achieved by the involvement of the users in specific field test in which the PROTECTOR application have been simulated and evaluated by interview campaigns.

The User Needs Survey was conducted in August 2000 in Germany and in September 2000 in Italy. In both countries 200 subjects answered the questionnaire. The questionnaire was laid out as a multimedia application

written in the Java programming language on a Windows computer. The advantage of making use of multimedia applications is to display a digital video clip with the driver situations and situation-specific questions at the same time on a computer monitor. The visualisation gives the subjects a vivid description of the relevant traffic scenario and helps them to classify the functions under investigation.

Another advantage of the computer-aided approach is the fact that the questionnaire was practically self administered and allowed a larger sample of subjects. A snapshot of the presentation of the questionnaire on the computer monitor is shown in the figure below.

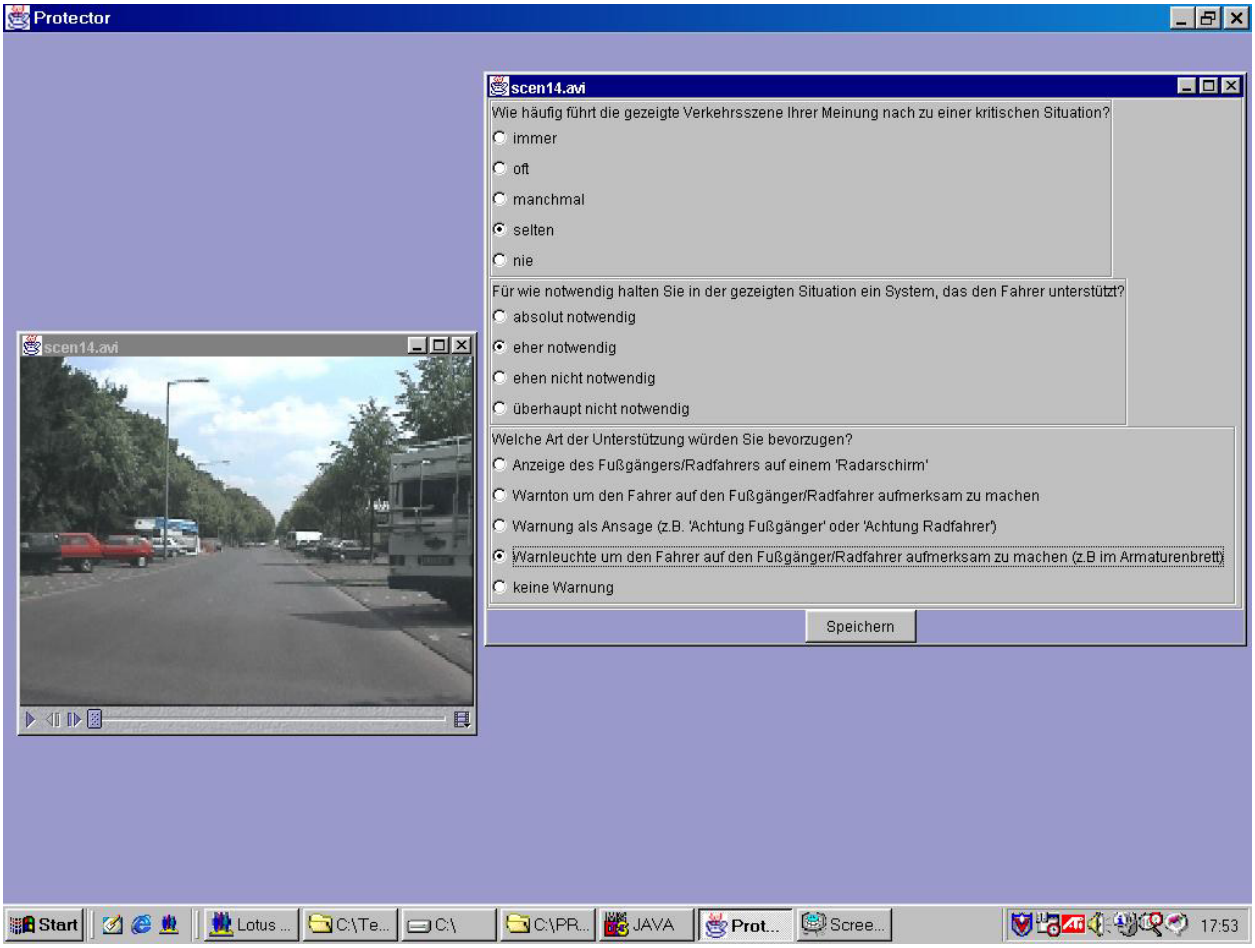



Figure 2: Snapshot of the multimedia questionnaire

The Consortium developed demonstrator vehicles, based on commercial vehicle and cars, allowing the early involvement of possible end-users from the beginning of the project. Thus it has been possible to work in parallel on system safety, system architecture and users interaction tasks in iterative steps to improve continuously the final product considering the end user requirements.

Designed as a Safety System it is necessary to take special care of the human-machine interface and interaction. State-of-the-art on-board displays

with visual and audible feedback are used and adopted to fulfil the requirements as far as possible.

Finally the development of the dedicated test site, the demonstrators and the workshops on the test site with the possibility of direct feedback from decision makers of the candidate Supply Industries is the final step to broadcast the PROTECTOR system concept and to enhance the public awareness about the project advantages.

The Evaluation procedure can be summarized by the figure 3, which shows a flow diagram of this procedure. In brief, without considering the tests of first year for the definition of user needs and requirements, the evaluation process is composed of three experimentation events:

Functional tests

- operational tests;
- verification tests;

These experimentation phases allowed for collection of information needed by the evaluation procedure. Source of information can be classified in three categories:

- hard data;
- soft data;
- simulated data;

The PROTECTOR project collected information by the following means:

Hard data

- on board sensors (data logger);
- on board ECU (central processing unit);
- on board video camera (video camera for external recording in longitudinal direction);

Soft data

- questionnaires;
- interviews;
- observation check lists;

The analysis of data coming from different sources was lead mainly in terms of statistical analysis; where appropriate, statistical tests were adopted in relation with the type of indicator measured and the type of source of information. The choice of statistical procedures was evaluated upon the basis of the quality of the data collected.

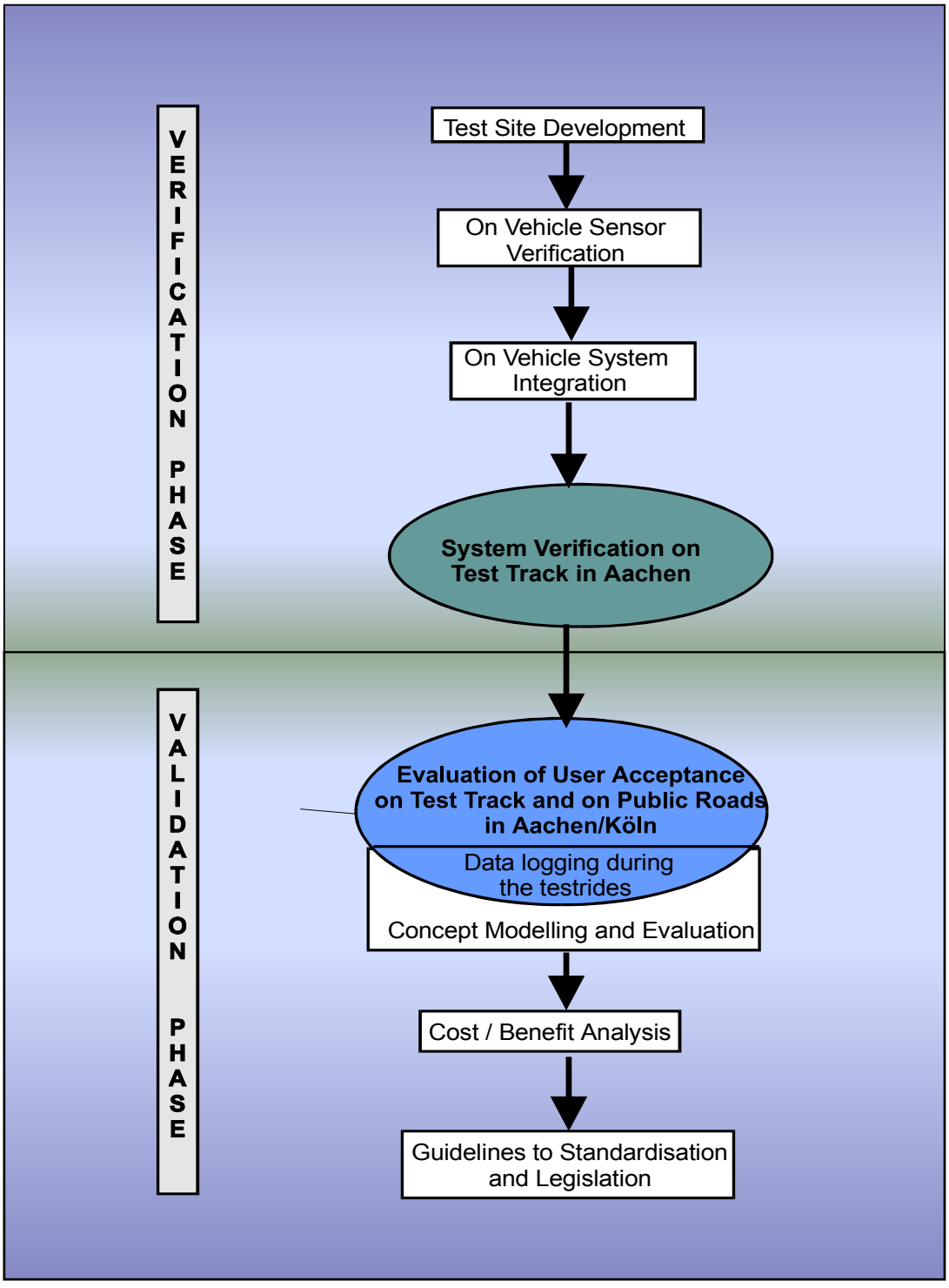



Figure 3: The evaluation process used in the project

## *1.4 Consortium's composition and the roles*

| Status | Participant name | Short name | Country | Part. Role |
|---|---|---|---|---|
| Car maker | Centro Ricerche Fiat S.C.p.A. | CRF | I | CRF built a medium class car with the protector functionality, contributed to the HMI specification and project management. |
| Car maker | DaimlerChrysler AG | DC | D | DaimlerChrysler built a premium class car with the PROTECTOR functionality and supported the project in specification work and sensor supply |
| Car maker | MAN Nutzfahrzeuge AG | MAN | D | MAN built a heavy truck with the PROTECTOR functionality |
| Supplier | IBEO Lasertechnik Hipp KG | IBEO | D | IBEO contributed in specification work and sensor supply |
| Supplier | SIEMENS VDO | SIEMENS | D | Siemens supported the project in specification work and sensor supply |
| Research organisation | TÜV Kraftfahart GmbH | TÜV | D | TÜV designed experimental user needs analyses and evaluated field studies |
| University | Università di Pavia | DIS | I | DIS developed the risk assessment module and an off line vehicle control |
| Research organisation | Institut fuer Kraftfahrwesen Aachen | Ika | D | IKA supported the project with verification site for the field trials and evaluation field studies |
| Research organisation | Centro Studi sui Sistemi di Trasporto | CSST | I | CSST performed the evaluation work. |

# 2. Project results and achievements

## 2.1 Scientific and technological achievements

The project PROTECTOR has developed three demonstrator vehicles equipped with VRU detection systems, risk assessment module and HMI devices to achieve the VRU protection application. For the first time in Europe, the PROTECTOR project allowed to lead public tests in real traffic, with a group of independent drivers of a set of prototype vehicles equipped with on board, real time VRU classification systems. However, due to the high level of novelty of this approach, some cautions have been used during tests and the reader has to consider this when analysing the results. Nevertheless verification phase allowed to collect a very impressive amount of data, both objective and subjective, which permitted a reliable evaluation of the tested application. Furthermore, the collected database has been a good source of information for simulation activities that completed the analysis with the impact on traffic and on environment.

In the following paragraphs it will give a description of the demonstrator vehicles used to validate the PROTECTOR function, the results of the benchmarking for the possible PROTECTOR communication system, the description of the warning strategies designed for the application, the results on sensor and system test, and the results on user test.

### 2.1.1 MAN demonstrator

The MAN demonstrator is a semi trailer tractor type TG-A 460 XXL (460 HP, extra large cab), shown in Figure 4. It is equipped with three Siemens Automotive 24 GHz near distance sensing (NDS) Radar sensors mounted on the right side of the vehicle. The motivation for the use of several Radar modules placed on strategic positions of the vehicle is to achieve a seamless awareness system on the right side of the vehicle without blind zones.

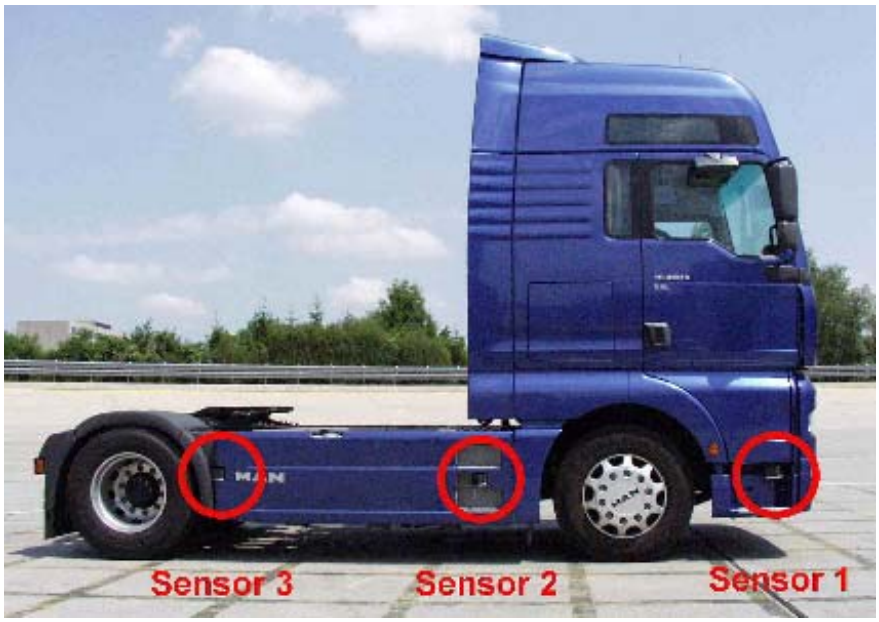



Figure 4: Demonstrator on heavy truck developed by MAN

### 2.1.2 DaimlerChrysler demonstrator

The demonstrator vehicle is a Mercedes-Benz E-Class station wagon shown in Figure 5.

Figure 5: The DaimlerChrysler demonstrator vehicle

It is equipped with an inverter module, converting the 12V direct voltage of the electric system of the car into 230V alternating (50Hz) voltage, which allows the DaimlerChrysler PROTECTOR demonstrator vehicle the use of "standard" electric devices (i.e. PC, Display) inside the car. Additionally an uninterrupted power supply unit maintains electricity for about five minutes, when the motor is switched off. Two non-interlacing digital cameras are installed near the interior mirror (Figure 6) facing the detection area. The distance between the cameras, the baseline, amounts to 25 cm. They are manually calibrated so that corresponding points of objects at infinite distance in front of the car meet the

same image coordinates in both cameras. Software synchronization ensures, that pairs of images are taken at the same time.

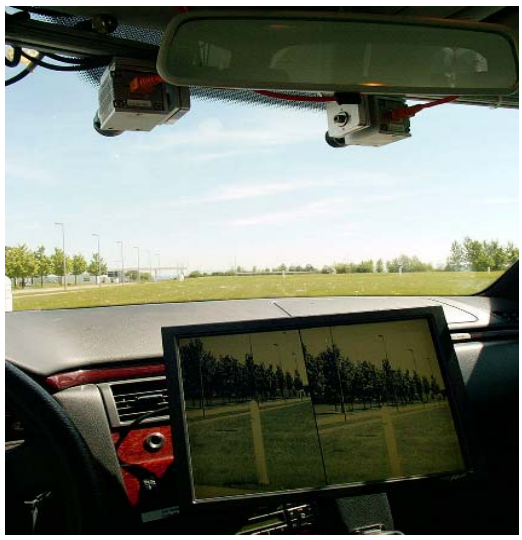


Figure 6: Video system

### 2.1.3 CRF demonstrator

The vehicle chosen by CRF to demonstrate PROTECTOR system functionality is an Alfa Romeo 147 - 2.0 with Selespeed (Figure 7). It is available on the market in a configuration equipped with CAN bus network and vehicle dynamics sensors (gyro meter and VDC connected sensors).

Figure 7: The CRF demonstrator vehicle

It is equipped with the new IBEO laser scanner LD Mulitlayer, a high-resolution scanner with an integrated DSP for sensor-internal signal pre-processing. The laser scanner emits pulses of near infrared light and measures the incoming reflections of those pulses. The distance to the target is directly proportional to the time between transmission and reception of the pulse. The scanning of the measurement beam is achieved via a rotating prism. The post-processing to calculate relative object speed and classification is done on an external Industrial PC. The application software is implemented on a MicroAutoBox from DSPACE, this solution allows a rapid prototyping environment. The internal HMI is guaranteed from a 7" display integrated in a radio/navigator system, while the external one is realised with 6 buzzers integrated in the front bumper.

### 2.1.4 Benchmarking for PROTECTOR communication system

Excluding systems based on visual detection (infrared lasers, etc), not of interest for the project, the three possible methods based on the transmission of radio waves to detect the target from the vehicle are based on the following techniques:

*radar (i.e. the target is passive),*

*passive transponders carried by the target,*

*active transponders carried by the target.*

Hereafter the main conclusions:

Electronic Toll Collection (passive transponders); the effective range (maximum distance *d*) has been estimated with reference to a scenario where a single target is present in the neighbourhood of the vehicle; by computing the link budget it is shown that a maximum range of about 30 metres is achieved only with a too large the antenna gain and this suggests the exclusion of this technology;

Bluetooth (active transponders); the effects of multipath propagation and vehicle speeds have been considered from the physical point of view; it is shown via numerical computation that these effects are not limiting: the performance is determined by the power class of the terminals and the range of 30 metres can be obtained only by considering class 1 or 2 terminals.

Cellular networks (active transponders); the capacity of the GPRS network has been compared with the requirements of the application, in order to assess the number of users that could be supported by a GPRS cell. It is concluded that only if a small service penetration is assumed, the service based on GPRS could provide the requested promptness.

As a conclusion of numerical investigations, it seems that the Bluetooth technology could be a candidate to fulfil the requirements of the application in the next future. In any case, the higher power class terminals should be used.

### 2.1.5 Warning and Control Strategies

The role of the Risk Assessment Unit is to select from the database, relying on the information relevant to the target and scenario type and on the vehicle speed and the target relative position arriving from the sensors, the function corresponding to the current situation. Then, on the basis of the selected function, the conflict risk probability value is determined. Taking into account all the previous considerations, the conceptual scheme of the Risk Assessment Unit is shown in Figure 8.

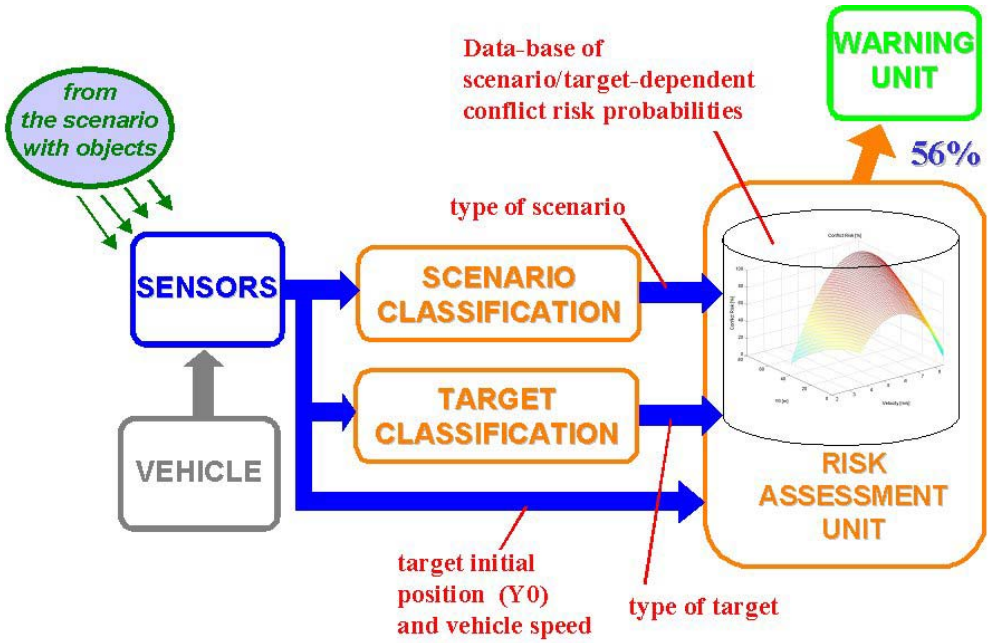



Figure 8: Conceptual scheme of the Risk Assessment Unit.

All the objectives have been attained satisfactorily. Of course further work is needed to come up with a version of the Risk Assessment properly working on the PROTECTOR vehicles. In particular, the conflict risk probabilities obtained as output from the Risk Assessment Unit are strongly scenario/situation dependent.

Moreover there are many other factors that can change the risk probabilities as pedestrian visibility, traffic lights (the colour of the traffic lights will influence the future behaviour of vehicles and pedestrians), and infrastructure obstacles. As an example for understanding the complexity, let us examine the nighttime visibility. In most cases, the nighttime visibility of a pedestrian is evaluated according to the driver's strategy and tactics.

The visibility of a pedestrian for drivers at night depends on several factors. The lighter the clothing, the easier it is normally to see the pedestrian. Reflectors on the clothing (often seen on joggers) can enhance the visibility of pedestrians. The type and intensity of street lighting can affect the nighttime visibility of pedestrians. Allen and others conducted a nighttime visibility study

to determine the actual pedestrian visibility and the pedestrian's estimate of his own visibility. Actual pedestrian visibility for normal dark clothing was about 53 m. Only the most pessimistic pedestrian estimated his visibility to be so poor. The average pedestrian thought her/his visibility was 105 m. Actual pedestrian visibility was enhanced to about 240 m by using reflectorised clothing. High-beam headlights will also increase pedestrian visibility.

If information about infrastructures and others influencing details could be available, the risk values would change drastically. Indeed, infrastructure information (road boundaries, pavement location, centreline, etc.) and other object information (e.g. other vehicles approaching) are obviously needed if a control strategy should be suggested and an automatic control implemented on a prototype. In fact, more than one manoeuvre can be possible in each situation if only the observation of the target (i.e. its position and speed relative to the vehicle) is taken into consideration. However some movements may not be allowed both for hard constraints (environment obstacles, road boundaries, other vehicles approaching) and soft constraints (driving laws).

### 2.1.6 Results on Sensor and System Test

Within the PROTECTOR project a test site was developed. This test site contains a test catalogue with tests on a closed test track and tests in a real traffic environment. Within these tests the catalogue distinguishes between the verification of the environmental sensors and the overall system performance.

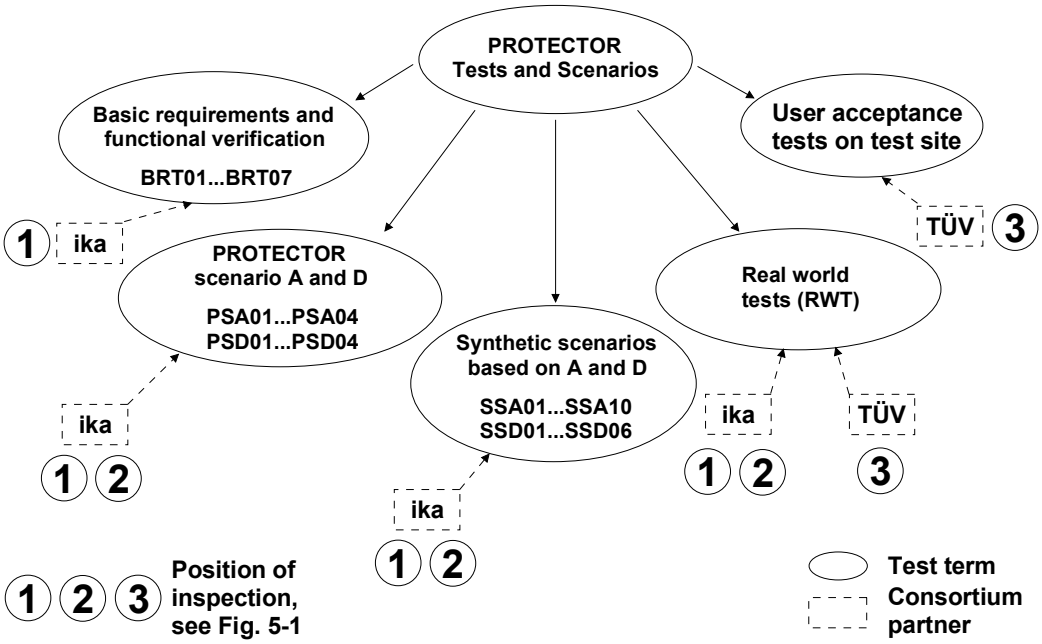



Figure 9: PROTECTOR sensor and system tests

Based on the above approach the PROTECTOR tests are structured into sensor and system tests, shown in Fig. 9.

### 2.1.6.1 The sensor test results

The sensor tests are called basic requirement tests (BRT) and verify the sensor accuracy and horizontal sensor coverage area.

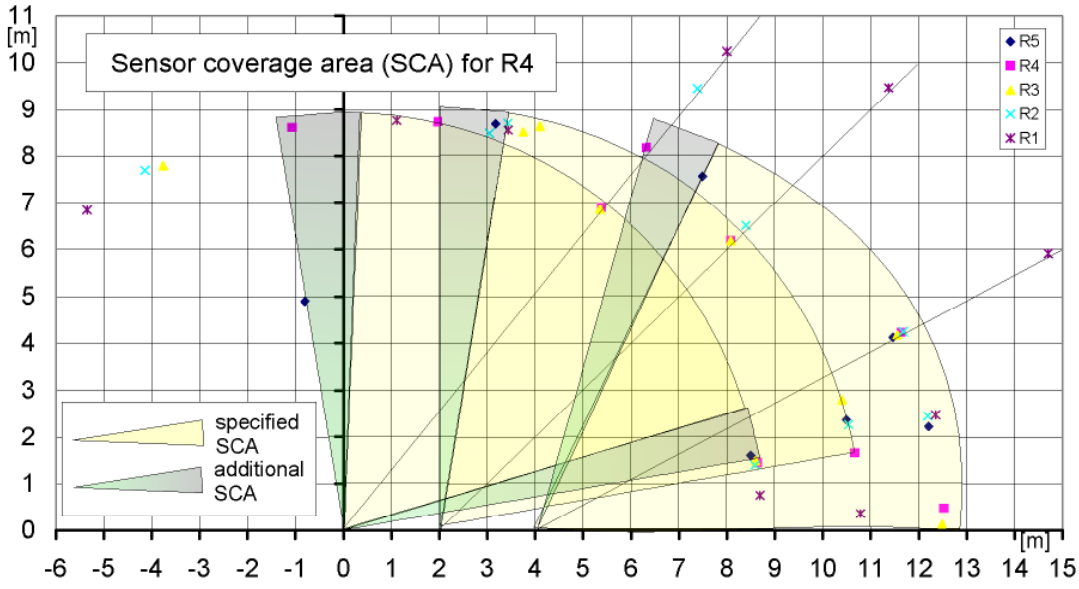



Figure 10: MAN sensor coverage area for small reflector size (R4)

Hereafter an example of the basic requirement test

- Sensor-Range: 8,50 – 8,75 m (for target R3 to R5)
  12,20 – 13,40 m (for target R1)
- Distance deviation < 0,3 m (for target R3 - R5)
- Aperture angle dep. on reflector size

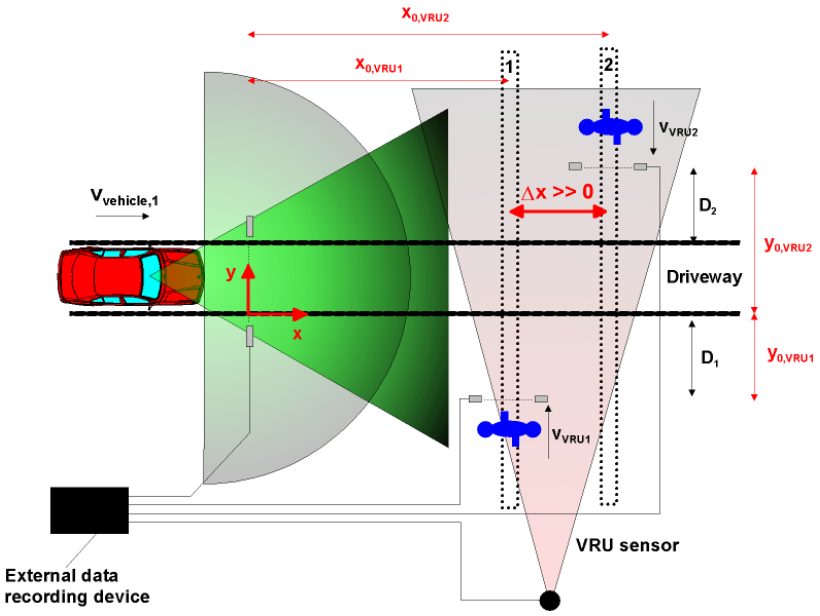
Particular Occurrences: Large Reflectors (R1/R2) are always detected as multiple objects in multiple distances

As result all sensor systems were successfully able to demonstrate proof of concept of VRU detection/classification.

### 2.1.6.2 The system test results

The system tests are called PROTECTOR Scenario A and D (PSA/PSD) and synthetic scenario (SSA and SSD). SSA and SSD are enlargements of PSA/PSD and based on scenario A and D. The scenarios verify the behaviour of the RAM (risk assessment module) and give information about the sensors under more difficult but still reproducible conditions. For the execution of the scenarios real pedestrian and cyclists are used together with additional targets like roadside objects and cars. Both, basic tests (BRT) and scenarios (SSA/SSD), are performed on a closed test track.

Hereafter an example of the Synthetic scenario test




- $v_{vehicle}$ 30 km/h
- $v_{ped.}$ 1 and 2 m/s
- comparison of pedestrian position with ground truth position given from seconary measuring equipment

Figure 11: Setup with two pedestrians crossing with large longitudinal offset

Regarding the scenarios performed on the test track the comparison of the vision system output with the data of the secondary measuring equipment delivers for an exemplary evaluation the following figures. In these figures the lateral and longitudinal positions given from the vision system (blue and magenta dots) and from the secondary measuring equipment (continuous lines) are printed over time. Beyond the entry and exit points of the demonstrator in the measuring path are marked.

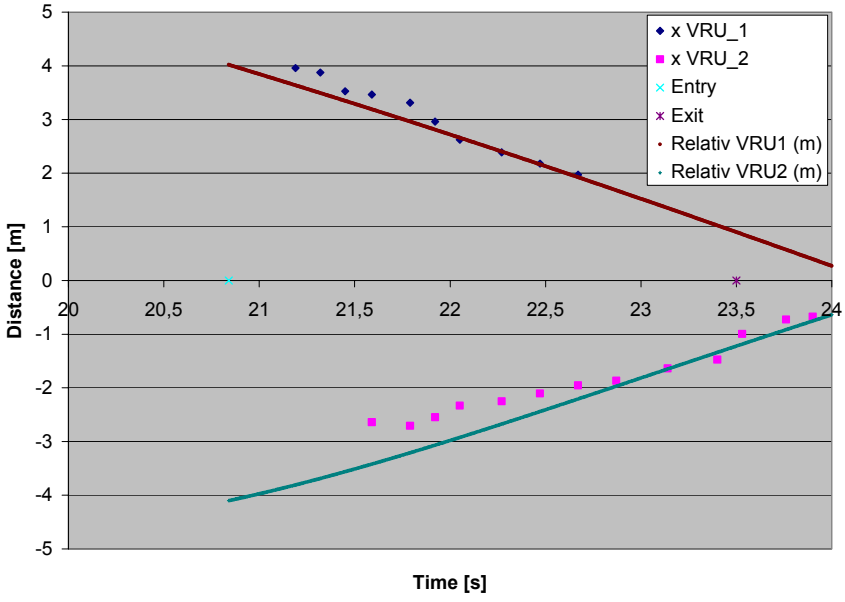



Figure 12: Time history of the relative position in lateral direction in the setup with two pedestrians crossing

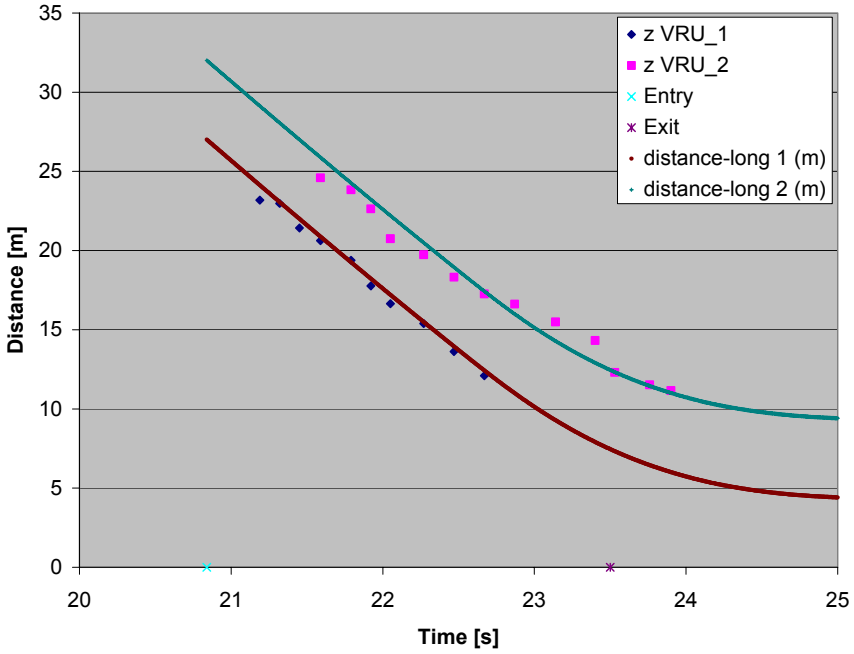



Figure 13: Time history of relative position in longitudinal direction in the setup with two pedestrians crossing

As one of the last steps of the technical tests the catalogue contains real world tests for the verification of the sensor false/correct/missing detection rate under realistic traffic conditions.

The real world test circuit can be summarized in the statement that this test course should be representative for a common urban area, starting and ending at ika and taking approximately 30 min for one measuring run. According to the different demonstrator vehicles and the different scenarios of interest (scenario A and D), two different circuits around Aachen are defined taking the below mentioned requirements into consideration. The selection of the test circuit involves a roadway arrangement with respect to the following aspects:

- Existing sidewalks / bikeways and buildings around the test circuit
- No country roads included
- Different road widths and lane numbers (wide and narrow roads with and without two-way traffic)
- Different frequency of VRUs (from no VRU up to groups of VRUs)
- Different directions of VRU movement are valid (crossing pedestrians for passenger car demonstrator of DC and CRF; for the MAN truck demonstrator only cyclists on the right edge of the road are of interest)
- Parking vehicles on the edge of the roads are valid

The RWT are performed with ika or the demonstrator builder test drivers. To guarantee comparable environmental conditions especially among the passenger car demonstrators, the tests are performed ideally parallel on the same day under dry conditions. A small amount of rain can be considered valid

if no spray is produced or dispersed by other vehicles. During the tests the drivers are briefed to avoid extreme acceleration or braking due to the occurring inaccuracies caused by pitch angles. The desired velocity for the RWT was specified to approximately 30 km/h by consortium agreement. The drivers are obliged to maintain this preset speed whenever possible and permitted by speed limits and with regards to the other surrounding traffic.

The RWT must not coerce other traffic participants and our test drivers are briefed to watch out carefully for pedestrians and cyclists in order to avoid any dangerous situation. In addition to the “normal” occurring VRUs 10 ika test persons take part in the traffic, performing street crossings or cycling along the street on the test circuit.

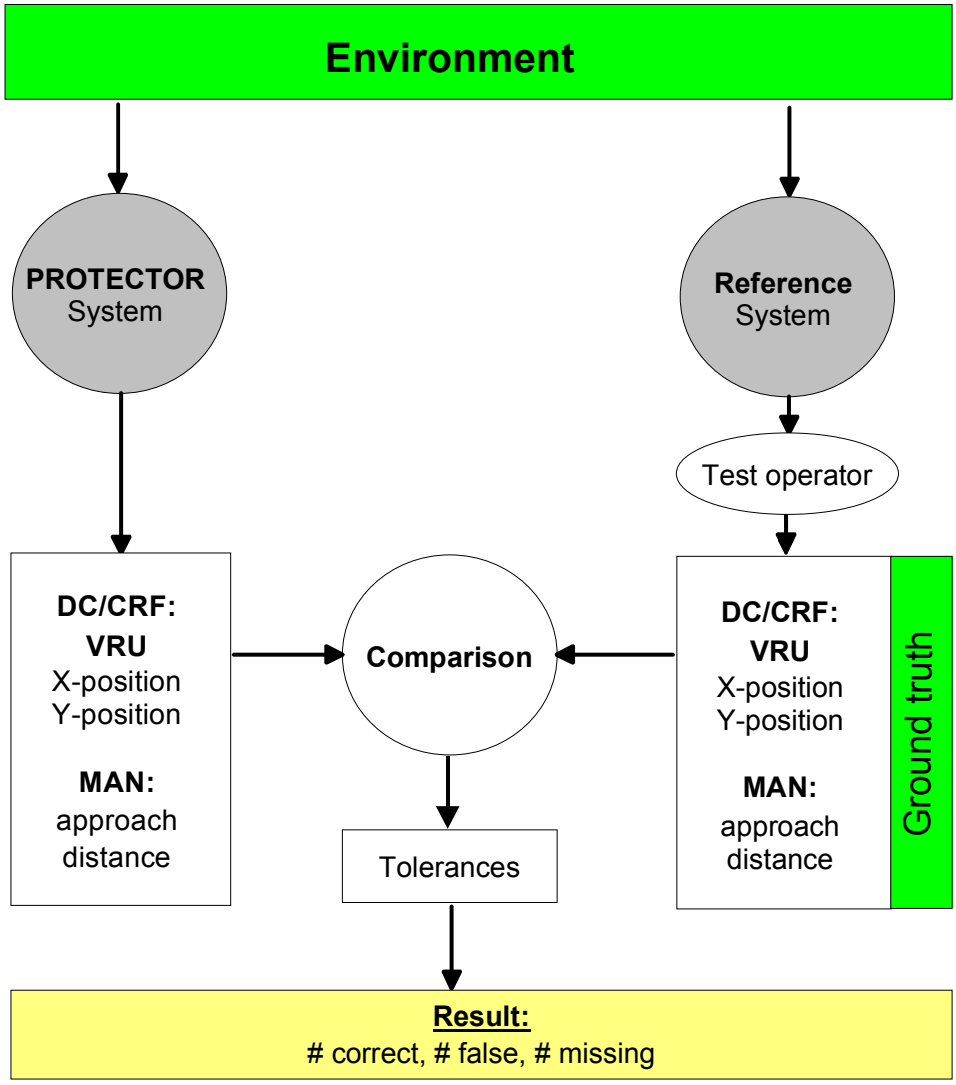



Figure 14: Real World Test logic scheme

The two runs performed were performed at different system parameter settings (Run1: "minimize false detections", Run2: "maximize the correct detections"). Detailed performance statistics are shown in table 1 and table 2, respectively, according to the terminology of section Terminology. For Run1 we obtain an object sensitivity of 0.32 and precision of 0.27. Trajectory-based, we have a

sensitivity of 0.45 and precision of 0.20. Going from Run1 to Run2, we see the expected effect of changed parameter settings: increased sensitivity, but decreased precision. For Run2 we obtain an object sensitivity of 0.43 and precision of 0.14. Trajectory-based, we have a sensitivity of 0.69 and precision of 0.10.

#### 2.1.6.3 Real world test: Comparison of laser and vision system

From the performed real world tests the following Table 1 and Table 2 show the achieved performance of both sensor technologies. The stereo-vision system detected/classified a fair 45% and 69% of all pedestrians on the road for the two runs of the RWT, respectively (per-scan detection rates were 32% and 43%, respectively). Two different parameter setting were used at each run, the first setting aimed to minimize the number of false detections, whereas the second was geared towards maximizing the correct detections. The average number of false detections/classifications, normalized per sensor scan (per image) was 0.025 and 0.082, respectively. Preliminary results show that using the risk assessment module as a filter can significantly further decrease the number of false detections/classifications.

Compared to the stereo vision system, the laser scanner system managed a higher per-scan detection/classification rate of 65% and 72% for the two RWT runs, respectively (no results are available on the fraction of different pedestrians detected). But on the downside, the average number of false detections, normalized per sensor (laser) scan became very large at 0.846 and 0.713, respectively.

| Run 1 | CRF<br>(laser scanner) | DC<br>(stereo vision) |
|---|---|---|
| Trial Duration | 1854 s | 1615 s |
| Avg. Processing Rate | 21.2 Hz | 13.2 Hz |
| Correct Detection Rate | 65% * (460/713) | 32% (153/485) |
| Correct Detection Rate<br>(pedestrian trajectory basis) | N/A | 45% |
| Avg Number of False Detections per message | 0.846<br>(30324/1691/21.2) | 0.025<br>(543/1615/13.2) |
| Avg Number of False Pedestrian Trajectories per sensor scan | N/A | 0.0054<br>(144–29)/1615/13.2 |

Table 1: Results for setup minimizing false detections (*based on the crossing ika pedestrian)

| Run 2 | CRF (laser scanner) | DC (stereo vision) |
|---|---|---|
| Trial Duration | 2089 s | 1432 s |
| Avg. Processing Rate | 21.4 Hz | 12.1 Hz |
| Correct Detection Rate | 72% * (554/771) | 43% (159/370) |
| Correct Detection Rate (pedestrian trajectory basis) | N/A | 69% |
| Avg Number of False Detections per message | 0.713 (26393/1729/21.4) | 0.082 (1427/1432/12.1) |
| Avg Number of False Pedestrian Trajectories per sensor scan | N/A | 0.016 (317–34)/1432/12.1 |

Table 2: Results for setup maximizing the correct detections (*based on the crossing ika pedestrian)

### 2.1.6.4 Real world test: results of microwave radar

According to defined procedure the two test runs for the RWT were performed on a Tuesday noon (5.11.2002). While performing the Real World Tests sensor 3 did not work correct. During the first test run it had three detections on cars, in the second test run it did not detect anything. But the failure of the third sensor did not influence sensor 1 and 2, so that the tests could be performed with the smaller sensor coverage area made up by the first two sensors. That did not impair the tests due to a testing concept evaluating the performance of each sensor independently.

| Evaluation truck demonstrator, 1. test run | | | | |
|---|---|---|---|---|
| | Approaching VRU | | Object within 2 m distance | |
| | Sensor 1 | Sensor 2 | Sensor 1 | Sensor 2 |
| Total number ground truth | 22 | 22 | 28 | 26 |
| System on VRU / on cars | 6 / 19 | 11 / 14 | 29 | 20 |
| # correct | 5 (23%) | 9 (41%) | 26 (93%) | 18 (65%) |
| # false | 1 | 2 | 3 | 2 |
| # missing | 17 (77%) | 13 (59%) | 2 (7%) | 8 (35%) |

Table 3: Event-based real word test evaluation for radar

The data evaluation made for sensor 1 and 2 is separated in the two tasks of detecting approaching VRU and detecting any object within a radius of two meters to the sensors. The evaluation for the two test runs is made in two different ways: event-based and time-based. The first test run of about 33 min is analysed event-based, see Table 3. Each of the system's detections (resp. missing detections) of approaching VRU or objects in the 2-meter-zone is counted as one event, independent of the duration. Due to the missing of object classification functionality, also approaching cars, trucks and motorbikes were detected. In this evaluation these detections are only contained in the total number of the PROTECTOR system.

In Table 3 the number of correct and missing detections is given as well as a percentage of the ground truth number. The sum of correct and false detection corresponds to the system's total number of detections.

## *2.2 User Test: General Results*

The objective of the user acceptance test was to examine the user's perception, assessment and acceptance of the PROTECTOR-System (in its current status). To differentiate in making judgements, data on three different levels had been gathered: on cognitive, emotional and motivational level. Furthermore it was asked for a general assessment of the system and an outlook on further development.

***First impression*** after the test ride was rather good for the MAN- and the DC-demonstrator, while most of the CRF-subjects were rather disappointed due to the constant warning ("…it warns always and for everything. The warnings are worthless"). The up to now unacceptable amount of false alarm was as well mentioned for the DC-demonstrator. However the idea and the approach made a good impression on most of the subjects.

For the **MAN**-demonstrator it was stated, that the warning could be earlier and more distinct and that the warning strategy (yellow/red level) should be over-worked. However the system was seen as a good base and close to marketable realisation. Especially the warning symbols in the mirror were seen as a felicitous solution.

For the **DC**-demonstrator it was pointed out, that the warning was too late. The acoustic warn signal was rated quite favourably. Few and far between it was assumed, that the sound might even be too pleasant (or too similar to the sound of the radio traffic news) for a warning sound.

The impression of the **CRF**-demonstrator was dominated by the false warnings. Most of the subjects experienced the visual warning as rather useless – it was pointed out that an acoustical warning would be enough.

All MAN-subjects and the vast majority of the DC-subjects (85%) but only less than the half (41%) of the CRF-subjects stated that their ***expectations*** of a system like the PROTECTOR-System were rather met (see fig. 15).

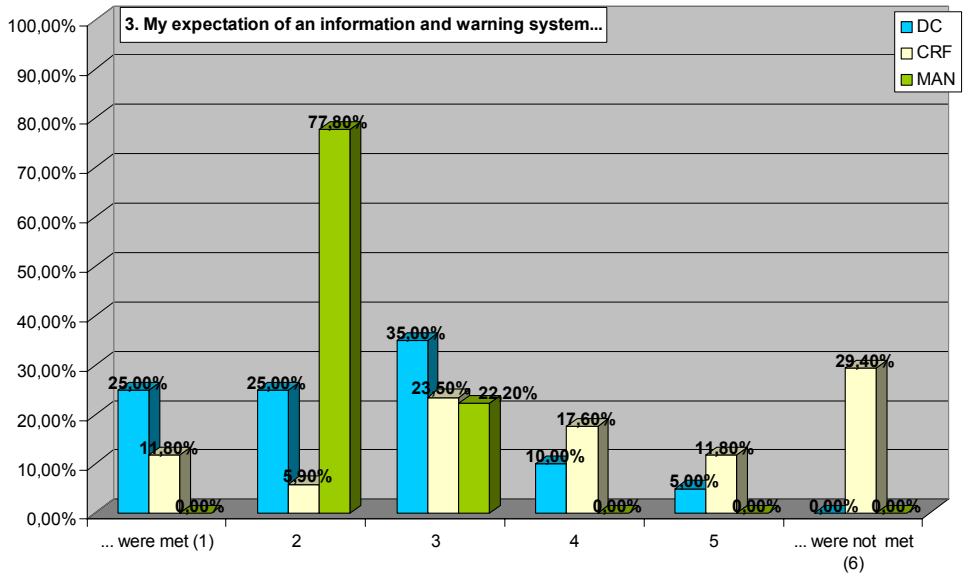



Figure 15: Expectations of users regarding an information and warning system.

The truck drivers (**MAN**) saw their expectations met because the system worked unobtrusive and without attracting attention, the warnings occurred in situations, when they were expected, there were only few false warnings and last but not least because it disburdens the driver and took away the uncertainty: “Is somebody there or not?”.

The car drivers (merely **DC**-subjects) who saw their expectations met gave as reasons, that the system actually warns, that it was at least sometimes helpful and seems to provide additional support and that it might save life (in a more sophisticated state). Those subjects (merely **CRF**-subjects) who did not find their expectations met, criticised that the system is still premature and therefore offers no useful information, but too many false warnings. The display was assessed as too distracting and the rapidly changing figures as irritating.

On the cognitive level three main areas were introduced: Operational framework understanding (comprehensibility: intuitive operation, awareness of the system’s performance and limits), learnability and system perception (visual and acoustical information).

### 2.2.1 Operational framework understanding and learnability

The ***system purpose and limitations*** seemed rather clear to most of the subjects. The ***learnability*** of the system function was rated very good. The

time needed to understand how the system works was assessed as rather short.

Concerning the ***intuitive operation***, about two-third (66%) of the truck drivers and three-quarter (75%) of the car drivers assumed that they would be able to understand the system without explanation.

The ***predictability***[1] of the systems reaction was assessed as *good predictable* to *rather predictable* by all MAN-subjects and by nearly all DC-subjects. For the CRF-subjects a less clear result was found: while more than half answered *good* to *rather predictable*, a good third answered *rather* to *poorly predictable*.

### 2.2.2 Visual and Acoustical Information

A ***visual warning in general*** was assessed as very sensible by the truck drivers but less so by the car drivers: only a narrow majority voted in favour of the visual warning, while the rest assessed it as rather not sensible to not sensible at all. An ***acoustical warning in general*** was invariably assessed as very sensible by all subjects (see fig. 16).

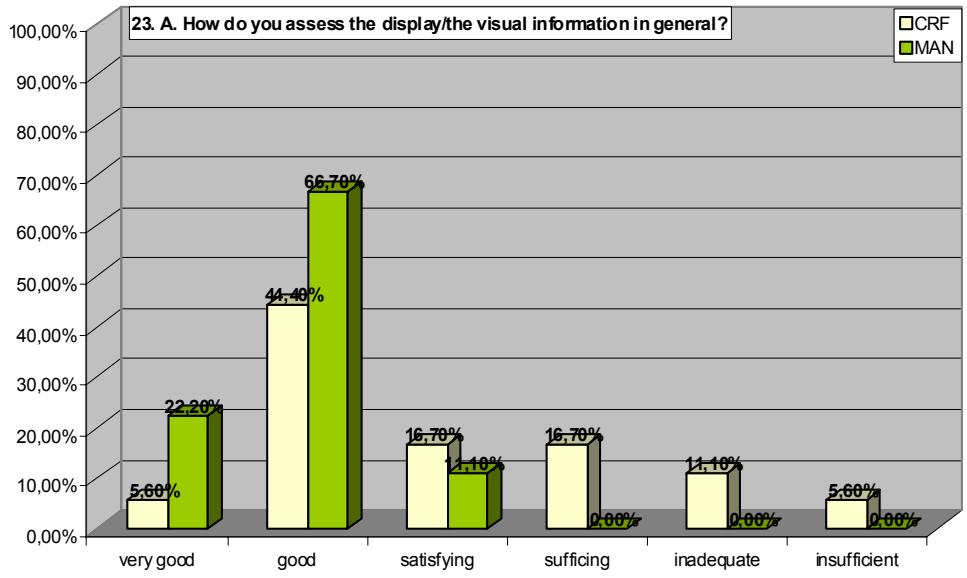



Figure 16: Overall assessment of the presented visual warning

#### 2.2.2.1 Acoustical Information of the PROTECTOR-System

The acoustical warning of the DC- and MAN-demonstrator was consistently assessed as pleasant, while about a third of the CRF-subjects assessed the

[1] It has to be pointed out here, that the predictability is not to be mistaken with the correct or false alarm rate. The results only indicate whether the system reacts in a way that can be predicted.

acoustical warning as rather unpleasant. It was assessed as rather clear by the majority of the CRF-/DC-subjects and by all MAN-subjects. The perception was assessed well by all DC-subjects and the majority of the CRF-subjects, but a third of the MAN-subjects assessed it as poorly perceivable.

The duration of the warning was assessed as exactly right with a tendency to too short by the CRF- and MAN-subjects. The volume of the warning was considered exactly right by all DC-subjects and most of the CRF-subjects, while it seemed to be too low for nearly half of the MAN-subjects.

In general they assessed the acoustical warning with an overall average grade of DC: 2,0 (good), CRF: 2,8 (satisfying) and MAN: 2,7 (good-satisfying) (see fig. 17).

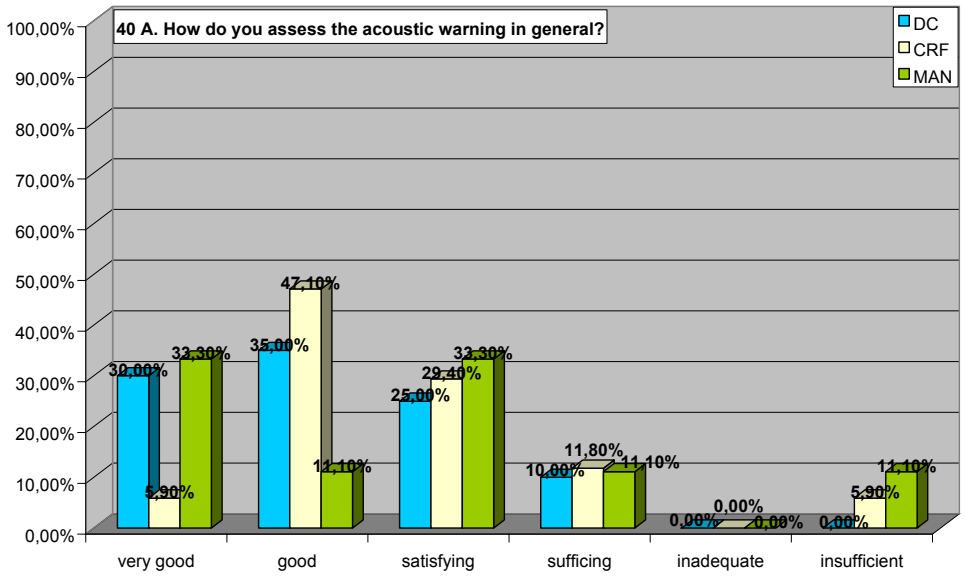



Figure 17: Overall assessment of the presented acoustical warning

All DC- and MAN-subjects felt (rather) not ***distracted*** by the acoustic warning, but about a quarter of the CRF-subjects did.

Asking for the ***most preferred kind of warning*** a majority of the DC- and CRF-subjects voted for acoustical warning only. The remainders had been in favour for visual and acoustical warning together. All MAN-subjects voted for the combined warning (see fig. 18).

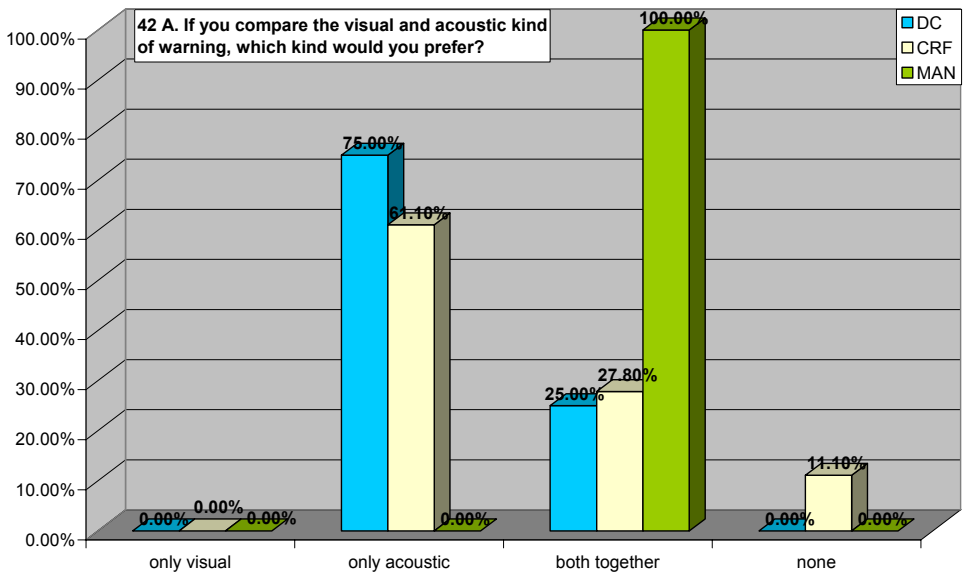



Figure 18: Preference of user regarding the type of warning

## 2.3 Results on emotional level

On the emotional level as well different categories are relevant: perceived safety, distraction effect and congruence of driver and system.

Concerning the possible ***distraction*** of a system like the PROTECTOR-System, the answers of the passenger car drivers widely disperse with a slight tendency to rather distracted for the CRF-subjects and to rather not distracted for the DC-subjects. However, a quarter (DC) resp. a third (CRF) of all car drivers estimated that they would be (very) distracted by a system like PROTECTOR. The majority of the truck-drivers estimated that they would not be distracted (see fig. 19)

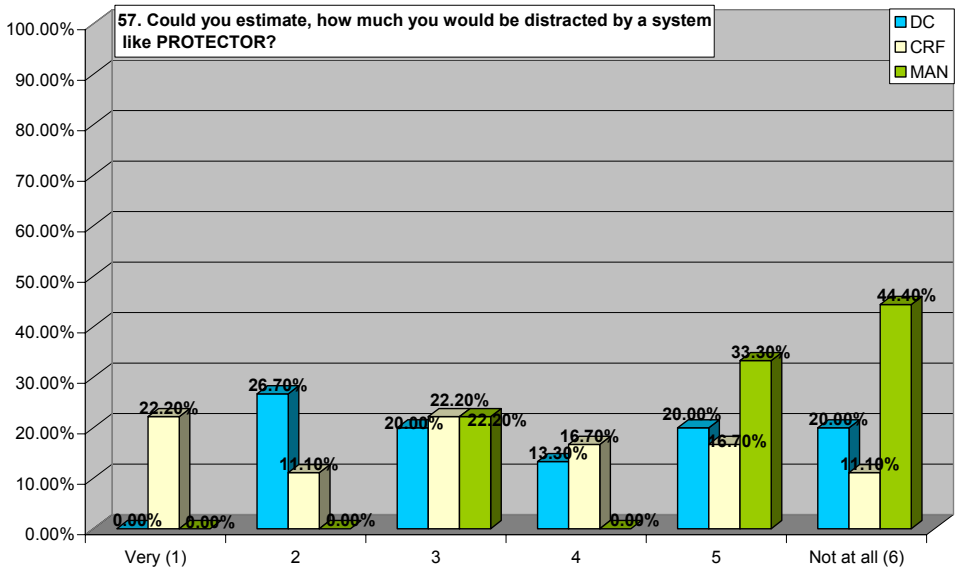



Figure 19: Feeling of user about distraction by a system like the PROTECTOR-System

The “index” of questions that more indirectly explores the ***risk compensation*** shows that about three-quarter of all subjects clearly disagree with five statements that suggest that the PROTECTOR-System enables the driver to drive faster or to do other things (e.g. reading a map) while driving.

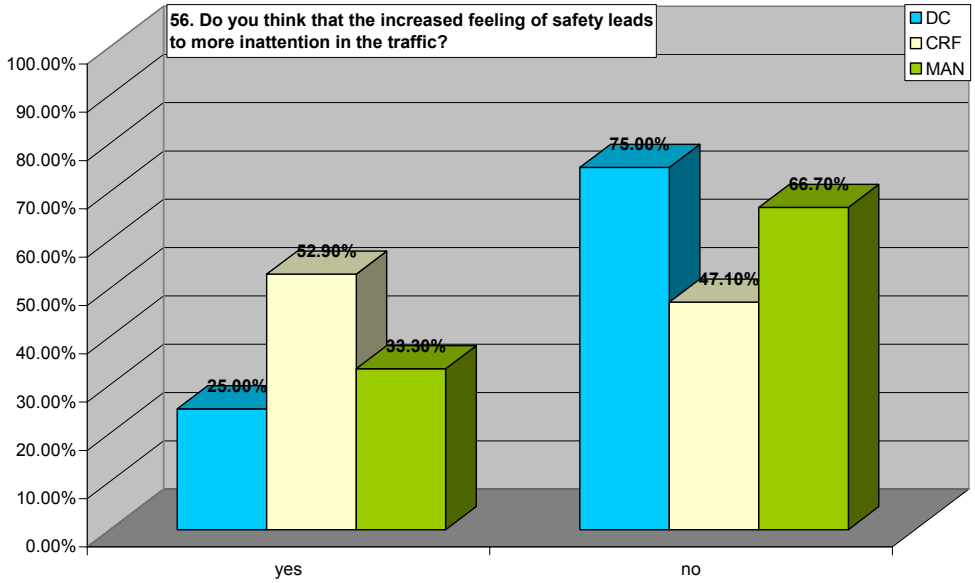



Figure 20: Risk compensation judgement

All MAN-subjects stated that they rather ***trust*** the system, while less than half of the DC-subjects and CRF-subjects did. For the CRF-subjects nearly a quarter stated that they did not trust the system at all.

All of the MAN-subjects and a large majority of the DC-subjects said that they felt rather more ***safe*** with an assistance system like PROTECTOR. For the CRF-subjects less than a half agreed. Figure 21 shows the full data.

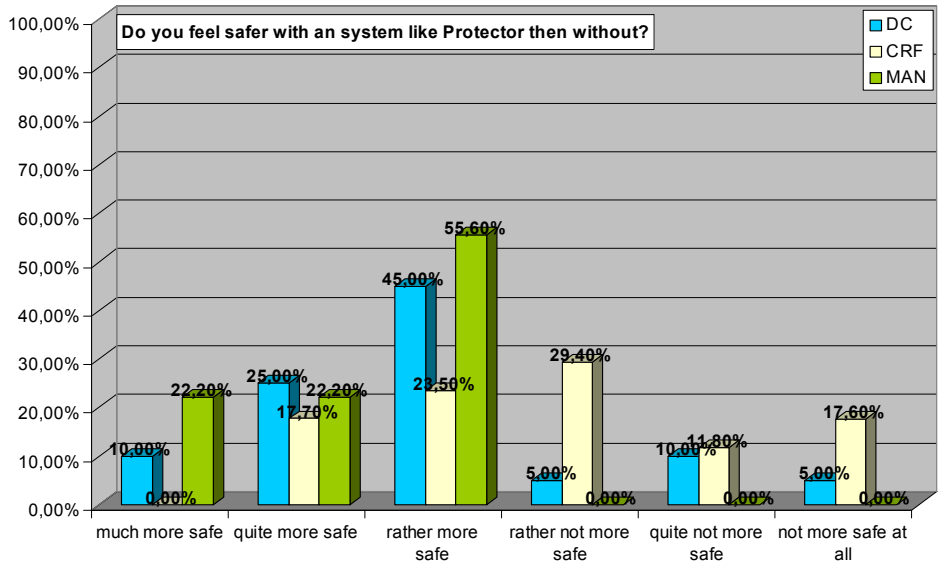



Figure 21: Perceived safety on PROTECTOR like system

Directly asked, the clear majority of the DC- and MAN-subjects answered, that they do not think, that the increased feeling of safety leads to more inattention in the traffic. The remaining third of the DC-/MAN-subjects and half of the CRF-subjects stated, that they think, it leads to more inattention.

The warning-point-of time showed for the DC- and CRF demonstrator vehicles a clear and for the CRF-demonstrator only slight tendency to be too late. For the later the majority assessed the warning-point-of time exactly right. Fig. 22 shows the results for the last Warning Situation on the test track (i.e. for the case that the dummy suddenly appears in front of the passenger car from behind a parked vehicle, resp. the sideways to the truck). The results are the recorded statements of the subjects after the situation.

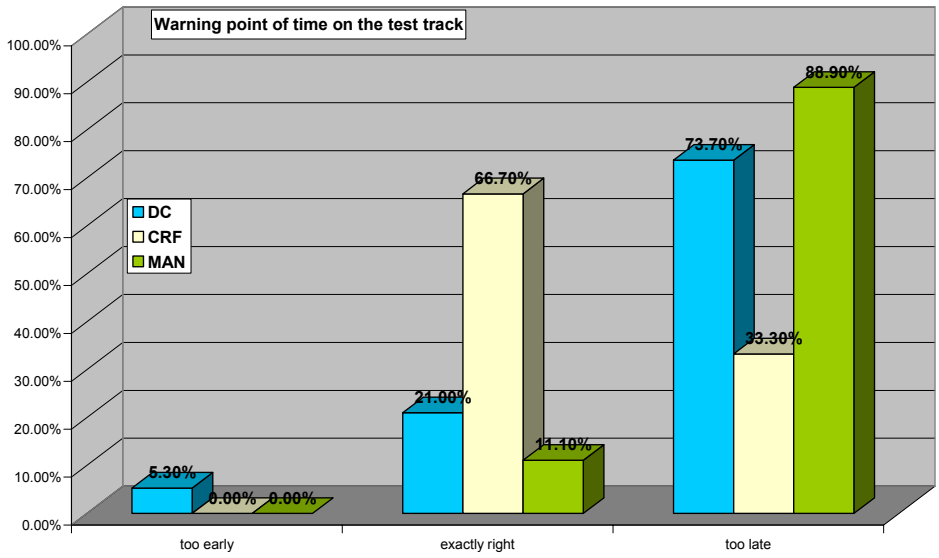



Figure 22: Assessment of the warning point-of-time

## 2.4 Results on motivational level

On the motivational level the attitudes toward the PROTECTOR-system (or systems with similar function) as well as the willingness to pay had been explored.

### 2.4.1 Attitudes toward the PROTECTOR-system

The overall assessment of the respective PROTECTOR-systems (rating in "school marks": 1 = *very good* to 6 = *insufficient*) varied:

the DC-subjects rated overall average grade of 2,9 (*satisfying*), the CRF-subjects rated it 4,0 (*sufficient*) and the MAN-subjects rated it 2,4 (*good*) (see fig. 23).

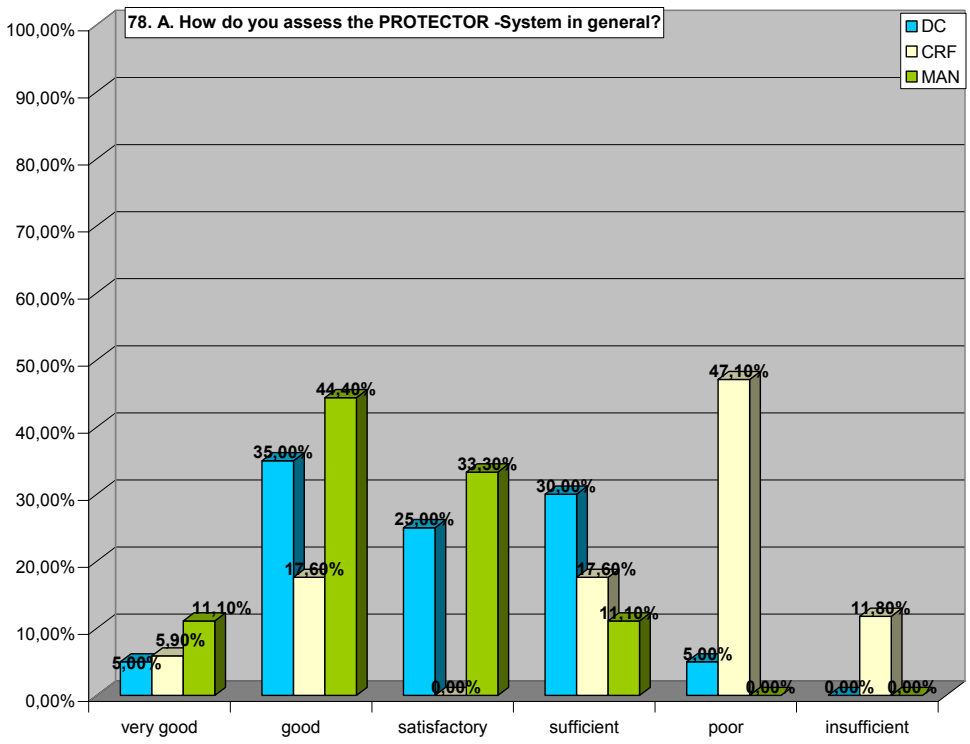



Figure 23: How do you assess the PROTECTOR-System in general?

## *2.5 Project deliverables*

The following table present the deliverables and milestones issued in the project.

| Deliverable Nr | Title | Security |
|---|---|---|
| D01.1 | Detailed project plan | IST |
| D02.1 | Accident analysis | PUB |
| D02.2 | Critical scenarios which will benefits from PROTECTOR | FP5 |
| D02.3 | User Needs investigation results | PUB |
| D02.4 | System Specification and Requirements | INT |
| M01 | Identification of the system concept | PUB |
| D03.1 | PROTECTOR Architecture Design | FP5 |
| D03.2 | Warning and Control Strategies | FP5 |
| D03.3 | HMI Guidelines | FP5 |
| D03.4 | Identification of the PROTECTOR Communication system | FP5 |
| M02 | System ready for installation | PUB |
| D04.1 | Test site development description | FP5 |
| D04.2 | Results and Conclusion for the Consortium Point of View | FP5 |
| D04.3 | Demonstrators and Vulnerable road users equipment description | FP5 |
| D04.4 | System Functional Verification results | FP5 |
| M03 | Three sensorial systems tested on the demonstrators according the technical specification | PUB |
| M04 | PROTECTOR application ready for demonstration/validation | PUB |
| D05.1 | Draft Validation Plan | FP5 |
| D05.2 | Verification and Validation Plan | FP5 |
| D05.3 | Validation Results | FP5 |
| D05.4 | Concept Modelling and Evaluation | PUB |
| D05.5 | Cost Benefits analysis | PUB |
| D05.6 | Guidelines for Standardisation and Legislation | PUB |
| D06.1 | Safety Issues and Risk Analysis | PUB |
| D06.2 | Dissemination Plan | PUB |
| D06.3 | Project Presentation | PUB |
| DO6.4 | Exploitation Plan | PUB |
| D06.5 | Final Report | PUB |
| M5 | Project Workshop | PUB |

# *3. Lesson learned and future developments*

A driver assistance system to prevent accidents with VRU is highly attractive. The majority of the subjects has shown high expectations and positive attitudes towards a PROTECTOR functionality even if they encountered systems that from a technical point of view, were still in an early stage of development.

Nevertheless some interesting conclusions can be drawn:

- the allowance for false alarm seems to be very low. If a driver experiences too many false alarms, he will ignore the warning. Therefore, one of the main conclusions is that successor projects to PROTECTOR need to focus on reducing this false alarm rate, while maintaining an acceptable VRU detection rate;

- the warning should be given early enough to allow the driver to react with proper awareness of the situation;

- the warning should be given acoustically – and the volume should be loud and long enough. A mere visual information is not sensible and possibly might rather decrease safety due to its distraction effect. A combination with visual information might be useful. Further research on the HMI is needed: while the display in the rear-view-mirror was positively assessed for the truck, the on-board display in the car appeared not to be helpful;

With regard to the three different demonstrators the following points should be considered:

The MAN-demonstrator seems to be on the right track from a user's point of view. The warning strategy (different levels as well as different pre-condition) should be reconsidered as well as the coverage area.

For the passenger cars, the DC-system generally was assessed more positive than the CRF-system – what is most likely due to the better sensor performance of the DC stereo vision system. Besides that, the basic system (warning sound only) of the DC-demonstrator appeared to be more appreciated than the elaborate one (voice, additional visual information, two-levels) of the CRF-demonstrator. However both systems are too premature (concerning system performance, coverage area and limitations) to state a final user judgement on the HMI.

Finally, one needs to realise, that although a lot of research still needs to be done, the results presented in this document represent an important first step towards the better development of VRU systems, and a better understanding of their impact on the user.

The following aspects need further investigation

- tolerance of false-alarms on the long run;
- the distraction effect of the PROTECTOR-System;
- the "ideal acoustical warning output": warning sound or voice, obtrusiveness of the sound (or general: individual choice of the sound);
- *potentially*: visual display in mirror or Head Up Display (especially for passenger cars);

The requirements of the truck drivers mainly refer to

- enlargement of the coverage to the driving cab, the rear axle and the back of the truck;
- higher sensitivity, but as well a minimum of false alarms;
- a clear distinction between VRU (resp. moving objects) and obstacles like parked cars;

The requirements of the passenger car drivers mainly refer to

- reliable recognition of different situations and thus reliable and correct system reaction;
- very few false warnings and no warnings in uncritical situations (to take the warnings seriously);
- support for and not compensation of the drivers, therefore earlier warning that allows a driver reaction in time;
- support especially for low visibility conditions (dusk/darkness, rain, fog);
- enlargement of the coverage to the back (for driving backwards) and to the side (for turning);

The tests performed within PROTECTOR allowed to identify some topics requiring future research:

- sensor performance needs improvement especially regarding the reduction of false alarm rate at a given detection rate and the increase of the sensor coverage area;
- sensor fusion (obstacle detection vs. object classification);vehicle control strategies for collision avoidance and mitigation (i.e. braking) should be investigated;
- bad visibility conditions (night, rain) should be considered.

# *4. Conclusions*

The PROTECTOR project, ended in March 03, has shown the technical feasibility and the benefits of VRU detection and classification, risk assessment and warning strategies, but also some existing limitations at present for such systems.

In summary, all **sensor systems** were successfully able to demonstrate a proof of concept for VRU detection/classification. For the first time, VRU detection systems were exposed to the very complex urban scenario, with promising results that advance the state-of-the-art. The main technical challenge ahead is to reduce the number of false detections while maintaining the correct detection rate at a reasonable level. The field tests suggested that the strengths of the radar and laser-scanner lie more in the area of VRU obstacle detection, whereas the stereo vision sensor is quite suitable for VRU object classification. The introduction of the **risk assessment** module has shown a relevant reduction of false warnings, thanks to the probability functions developed for this application. Of course further work is needed, in particular, the conflict risk probabilities obtained are strongly scenario/situation dependent. On the topic of the **Human Machine Interface**, a guideline has been generated, to channel future research activities. In fact some aspects still need to be investigated, as mentioned in the previous paragraph.

A significant outcome is that, the EU guidelines used in the design phase and in evaluation phase, have received a relevant contribution, so that to the general test methodology followed in the project can be taken as a reference for future work in this area.

Finally, sensor-fusion is an appealing option to increase the robustness of classification, and there is reason to be optimistic about VRU detection/classification progress.

# *5. Terminology*

| | |
|---|---|
| event | an object according to ground truth |
| alarm | an object according to detector system |
| required event | an event within the detection area |
| optional event | an event outside the detection area |
| good event | a required event with at least one matching alarm |
| good alarm | an alarm with at least one matching event (either required or optional) |
| event trajectory | a sequence of events with the same object id |
| alarm trajectory | a sequence of alarms with the same object id |
| event/alarm trajectory | an event/alarm trajectory with at least one good event/alarm |
| object sensitivity | number of good events divided by the total number of events |
| object precision | number of good alarms divided by the total number of alarms |
| trajectory sensitivity | number of trajectories with at least one match divided by the total number of trajectories according to ground truth |
| trajectory precision | number of trajectories with at least one match divided by the total number of trajectories generated by the system |