

# Pre-Impact Pedestrian Sensing

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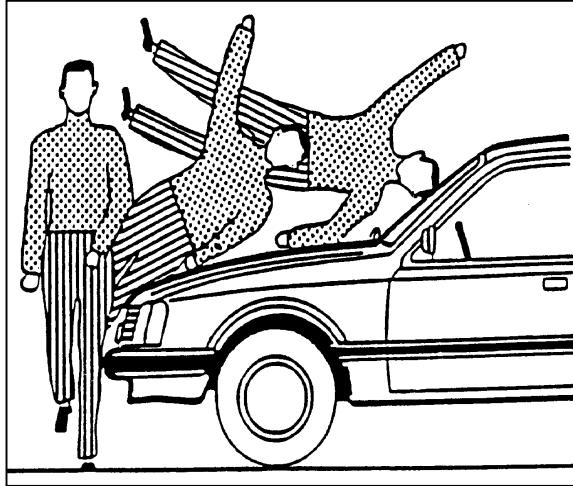
**Machine Perception**

**DaimlerChrysler Research & Technology**

**Ulm, Germany**

- Motivation - Pedestrian Protection - Video Sensing
- Competitive Landscape
- The PROTECTOR Project (01/00 - 03/03)
  - Vehicle Demonstrators (FIAT, MAN, DC)
  - DC System Specification
  - Sensor performance & user acceptance tests
  - PROTECTOR Conclusions
- The SAVE-U Project (03/02 - 02/05)
  - Project Scope, Comparison with PROTECTOR
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- References

# Motivation for Pedestrian Protection



- 155000 pedestrians injured, 6000 pedestrians killed yearly (EU wide)

Our long-term goal is to develop vision-based vehicle safety systems which anticipate dangerous situations involving pedestrians ahead of time and either warn the driver or, if no time remains, initiate emergency measures to minimize the impact of a collision (e.g. braking).



# Competitive Landscape “Pedestrian Sensing”

	Sensor Type	Coverage Area	Protection Concept	Recogniton Performance	Test Set	Processing Speed
<b>CMU (2000)</b>	stereo vision (visible)	frontal (bus)	-	85% correct 3% fpos (per ROI)	8400 instances ped + nonped	3-12 Hz (450 MHz)
<b>US Army + Univ. Parma (2003)</b>	stereo vision (visible)	frontal	-	-	-	-
<b>DaimlerChrysler (2003)</b>	stereo vision (visible)	frontal (10-25m)	Driver Warning	48% correct, 3% fpos (p. image), 64%-76% correct (p. traj)	26 runs test track + 2 x 30 min urban traffic	4-15 Hz (2.2 GHz)
<b>VW + Univ. of Parma (2003)</b>	mono vision (FIR)	frontal	-	-	-	-
<b>Toyota + MIT (2003)</b>	mono vision (FIR)	frontal	-	84% correct, 19% fpos (summer, p. image)	289 ped. images	-
<b>Honda + Ohio St. Univ. (2003)</b>	stereo vision (FIR)	frontal (10-35m)	-	-	-	-
<b>FIAT + IBEO (2003)</b>	laser scanner	frontal (3-30m)	Driver/Ped Warning	65%-72% correct, 71%-85% fpos (p. image)	26 runs test track + 2 x 30 min urban traffic	21 Hz



**Acronym:** PROTECTOR



**Full Title:** Preventive Safety for the Unprotected Road User

**Duration:** January 2000 - March 2003

**Partners:** FIAT, DC, MAN, IBEO, SiemensVDO, Univ. Pavia, CSST, IKA, TÜV

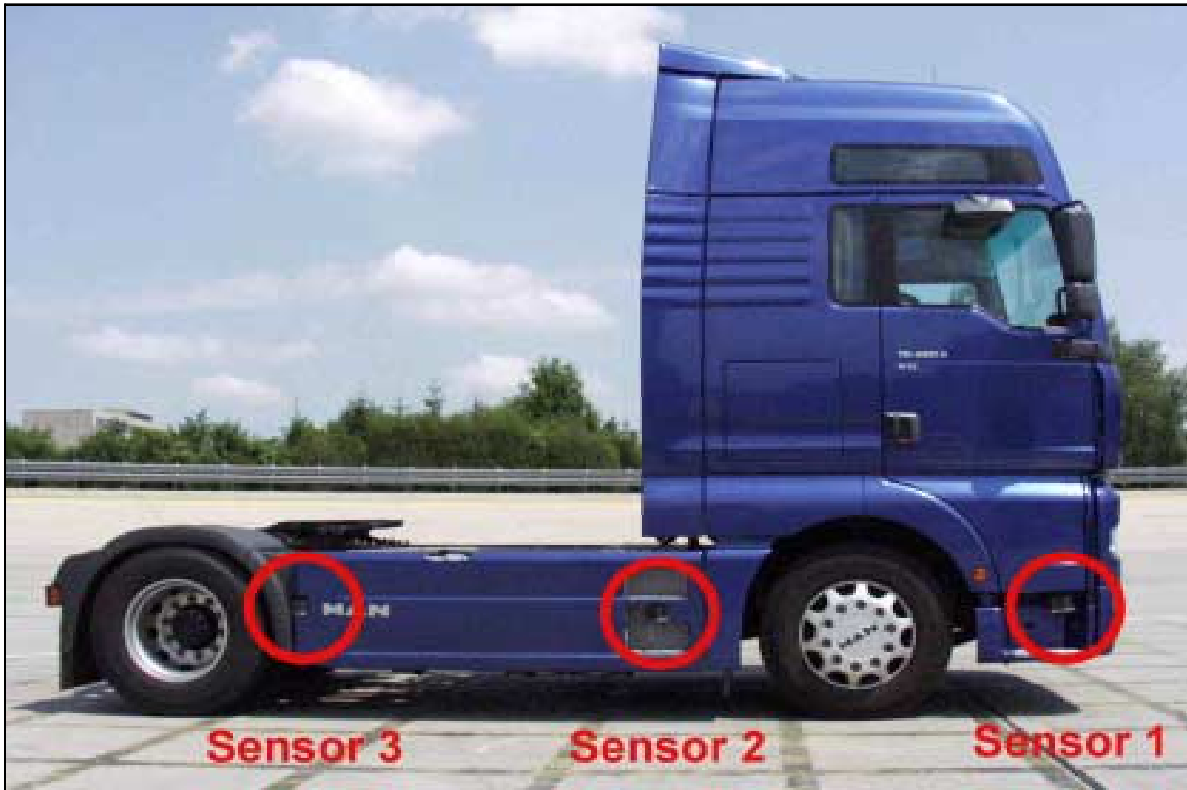
**Budget:** 4.5 M EUR, of which 772 K EUR for DC (4.5 person years)

**Scope:** Vulnerable road user protection using three sensor technologies: laser scanner, 24 GHz radar and stereo vision. Protection by driver and pedestrian warning.

**Demonstrators:**

- MAN truck with SiemensVDO 24 GHz radar (bicyclists)
- FIAT passenger car with IBEO laser scanner (pedestrians)
- DC passenger car with DC stereo vision (pedestrians)

**Web Site:** [www.protector-eu.org](http://www.protector-eu.org)



Close-up 24 GHz radar

Assist truck driver during right turn at intersection: warn for bicyclists that go straight.

## Outside Mirrors

Left

Right



### Information Situation

If object was detected by sensor 1 or sensor 2 within range 30-200 cm and the driver has activated blinker for right turn.



### Warning Situation

If object was detected by sensor 1 or sensor 2 within range 30-200 cm and the driver has turned the steering wheel more than 90° to the right)

(All symbols flashed)

... includes acoustic warning: bicycle bell



**Alfa Romeo 147 - 2.0 with Selespeed**



Left obstacle



Obstacle ahead



Right obstacle



Left obstacle



Obstacle ahead



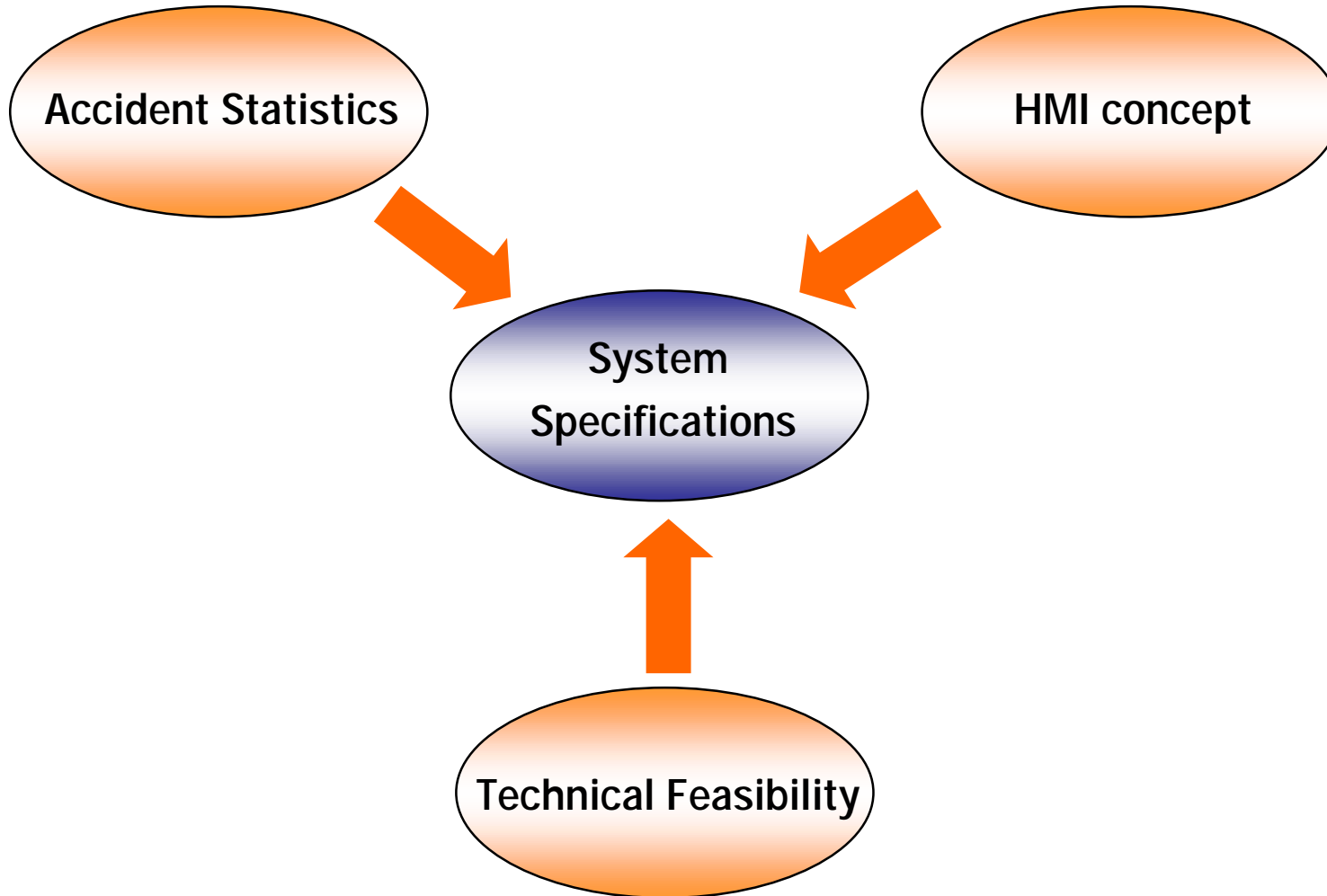
Right obstacle

## Driver HMI



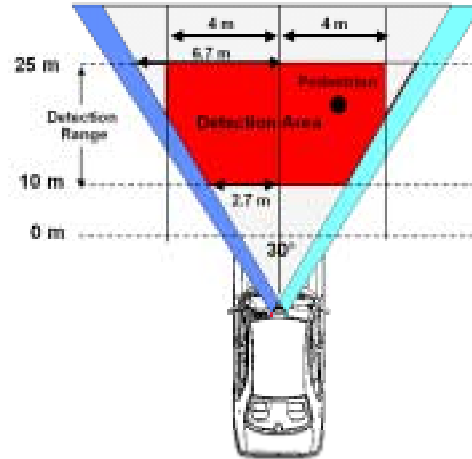
## Outside, Pedestrian HMI

external buzzer  
(if there is a RED level alarm and the accident probability is greater than a defined threshold)





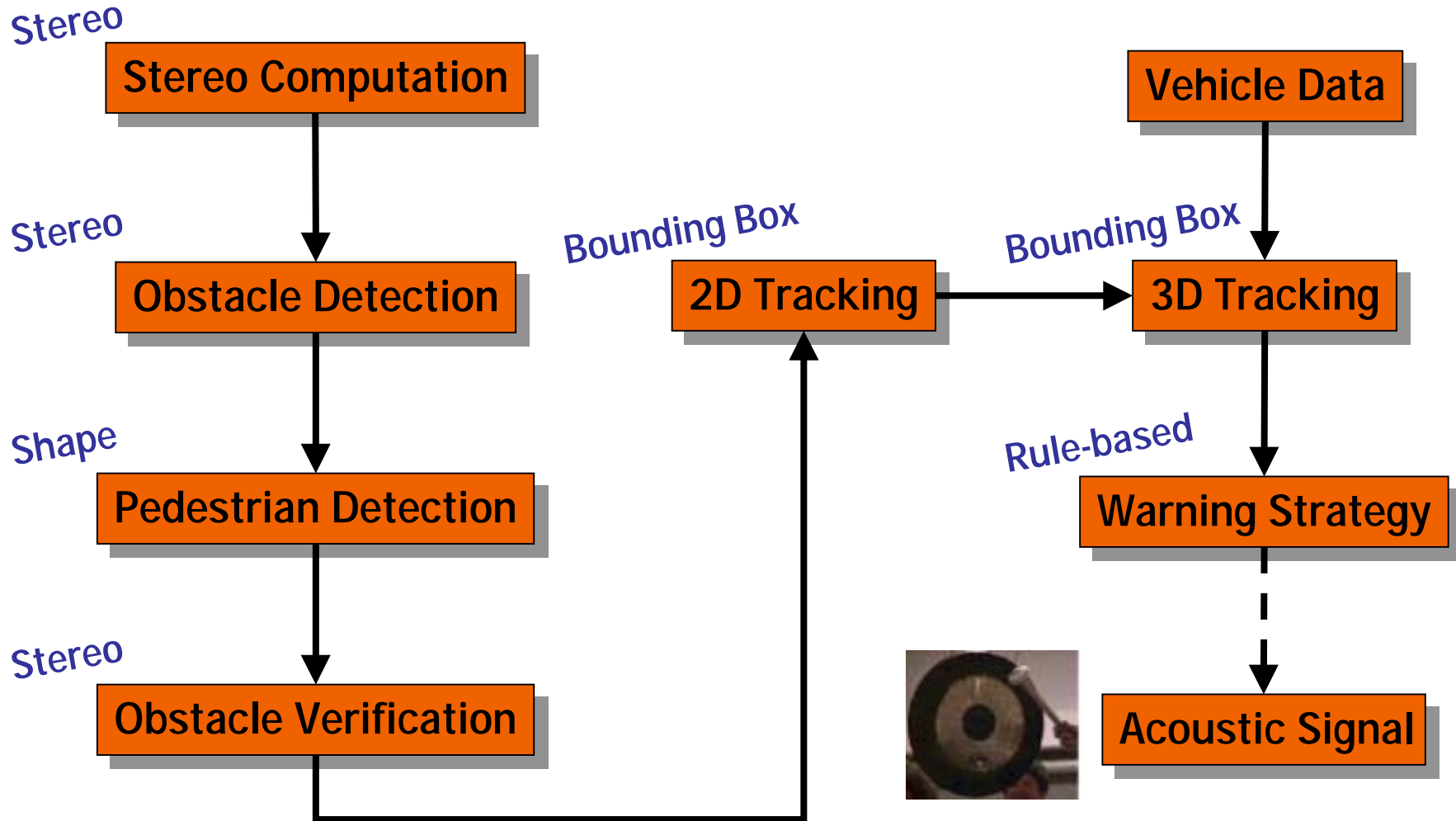
# PROTECTOR: DaimlerChrysler System Specifications



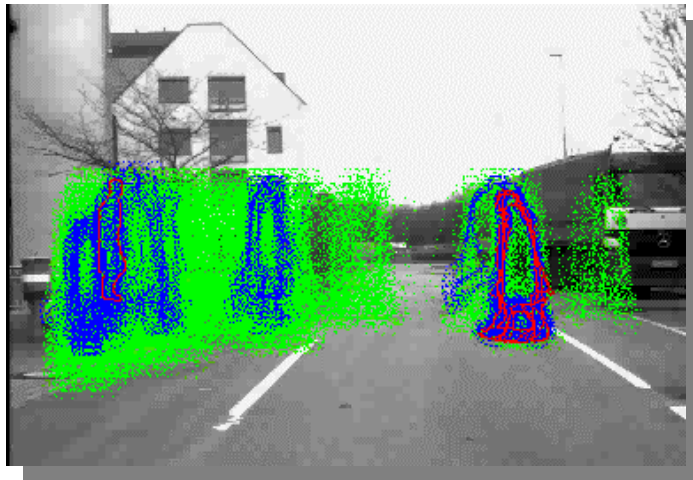
- **Target:** pedestrian
- **Sensor:** stereo vision, combining depth and shape cues, integrated over time
- **System Output:** Driver warning by acoustical warning signal
- **Detection range:** 10 - 25 m in front of vehicle and 2.7 - 4 m lateral, each side
- **Processing rate:** 4 - 15 Hz on 2.4 GHz Intel Pentium PC (Linux OS)
- **Environment conditions:** dry and light rain, daylight
- **Vehicle Speed:** 0 - 30 km/h



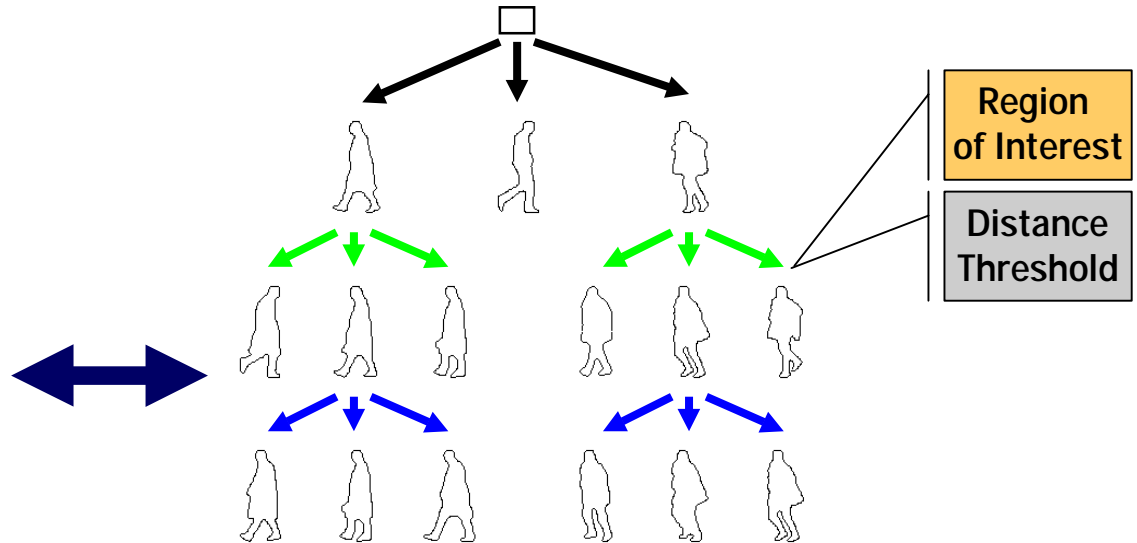
# DaimlerChrysler System Diagram



Combined Hierarchical Approach in Transformation and Shape Space



Coarse-to-fine Search



Template Hierarchy

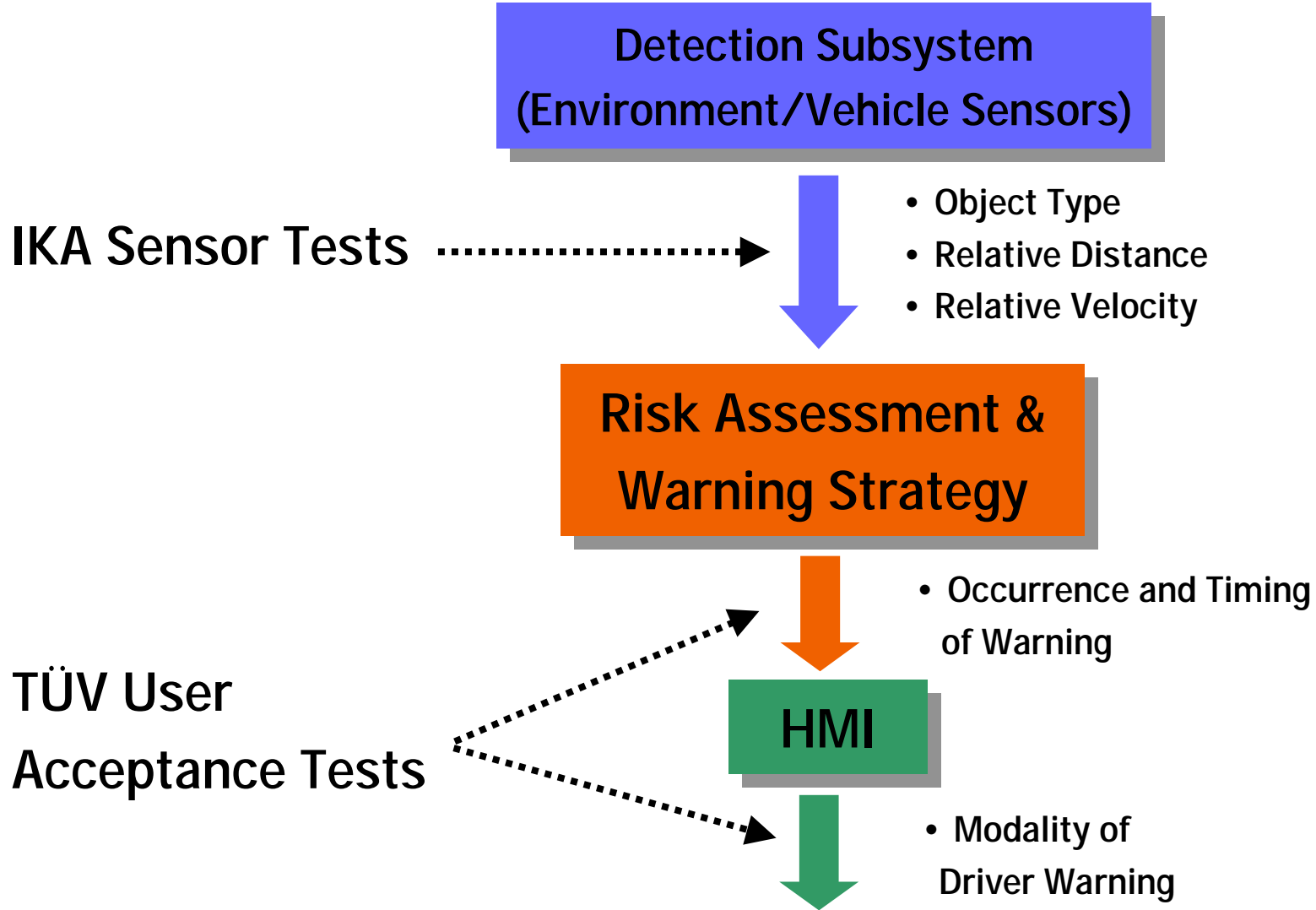
Speed-up compared to brute-force matching is typically several orders of magnitude!

Region of Interest

- prior scene knowledge
- outcome matching at parent node

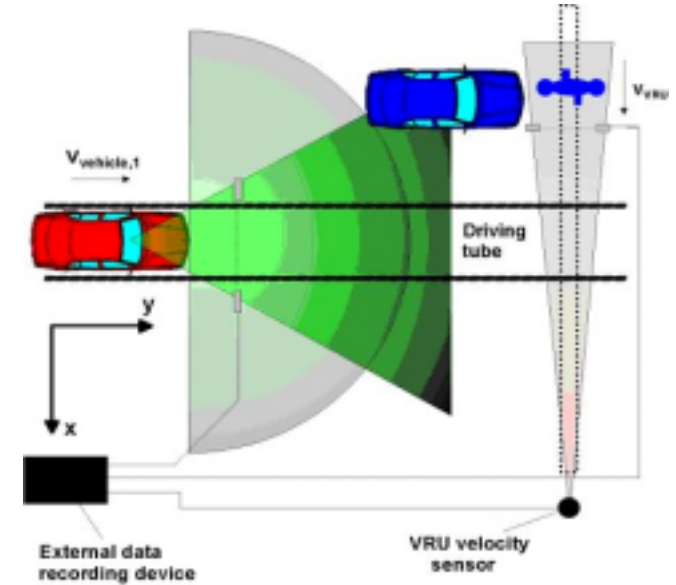
Distance Threshold

- shape variation tolerance
- segmentation errors
- granularity search grid
- dissimilarity to successors



## On IKA test track

- Basic testing: sensor coverage area
- “Synthetic” scenarios: laterally crossing pedestrians of various ages, walking speeds, clothing, with and without occlusions (18 tests).
- All system output logged
- Off-line evaluation of detection rate vs. false alarm rate, relative position and velocity accuracy (ground truth by auxiliary measuring equipment).

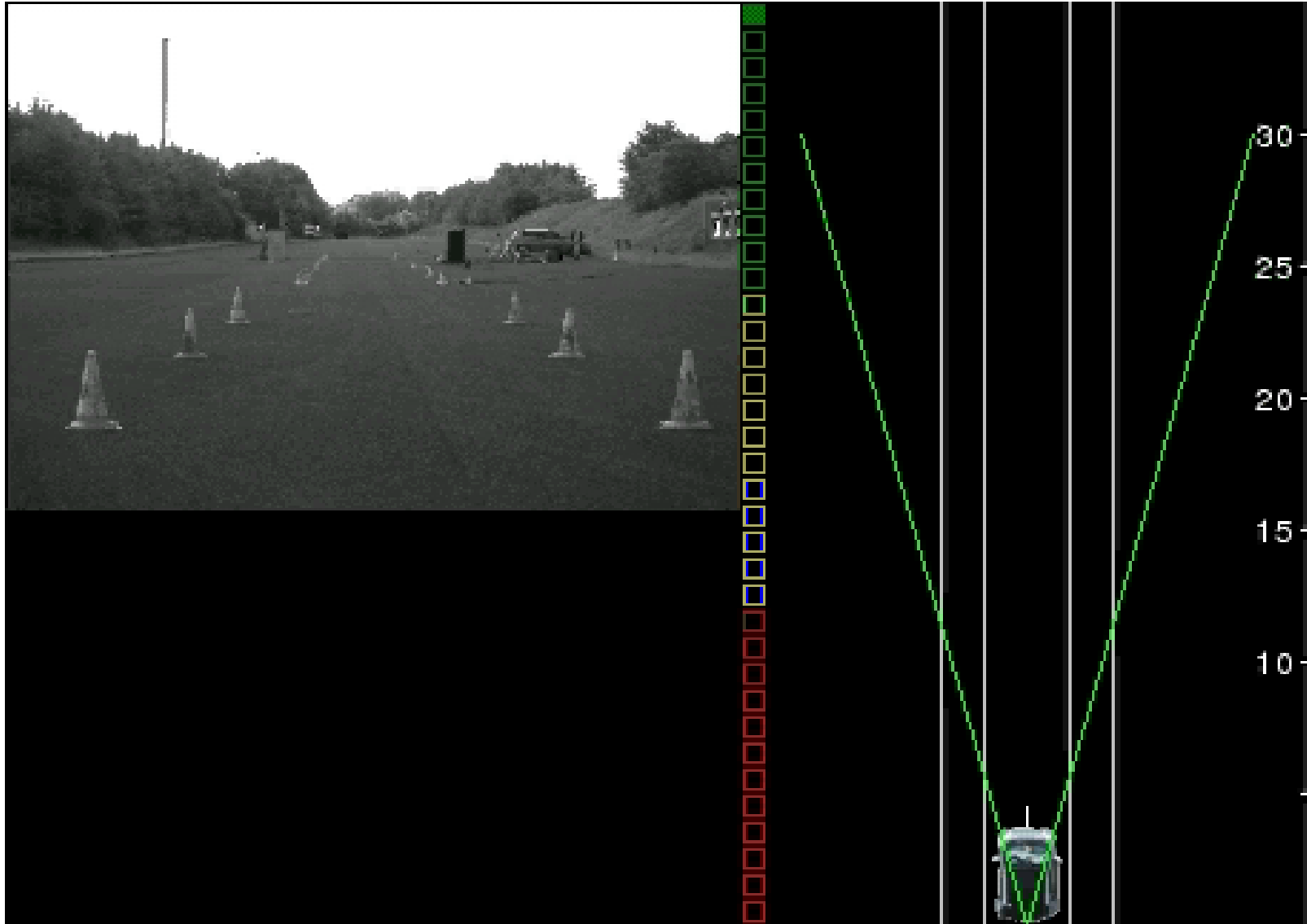


## In the city of Aachen

- 30 minute drive, “real-” and “IKA-” pedestrians
- All system output logged
- Off-line evaluation of detection rate vs. false alarm rate (“ground truth” by visual inspection)











- 20 subjects per passenger car (CRF, DC), mixed sex, age 22-77 years (mean 40)  
12 subjects per truck (MAN), only males, age 21 - 58 (mean 38)
- 120 minutes / subject

- Demo on parking lot
- Test drive in urban area
  - familiarizing with car and system
  - first impression of the system
- Test drive on test track
  - seven defined test situations (no-warning, information, warning)

## Pre-Questionnaire

- demographic data
- attitudes towards modern technology
- driving style

## Questionnaire User Manual

## Protocol during test drive

- driver comments, matching system behaviour and driver request

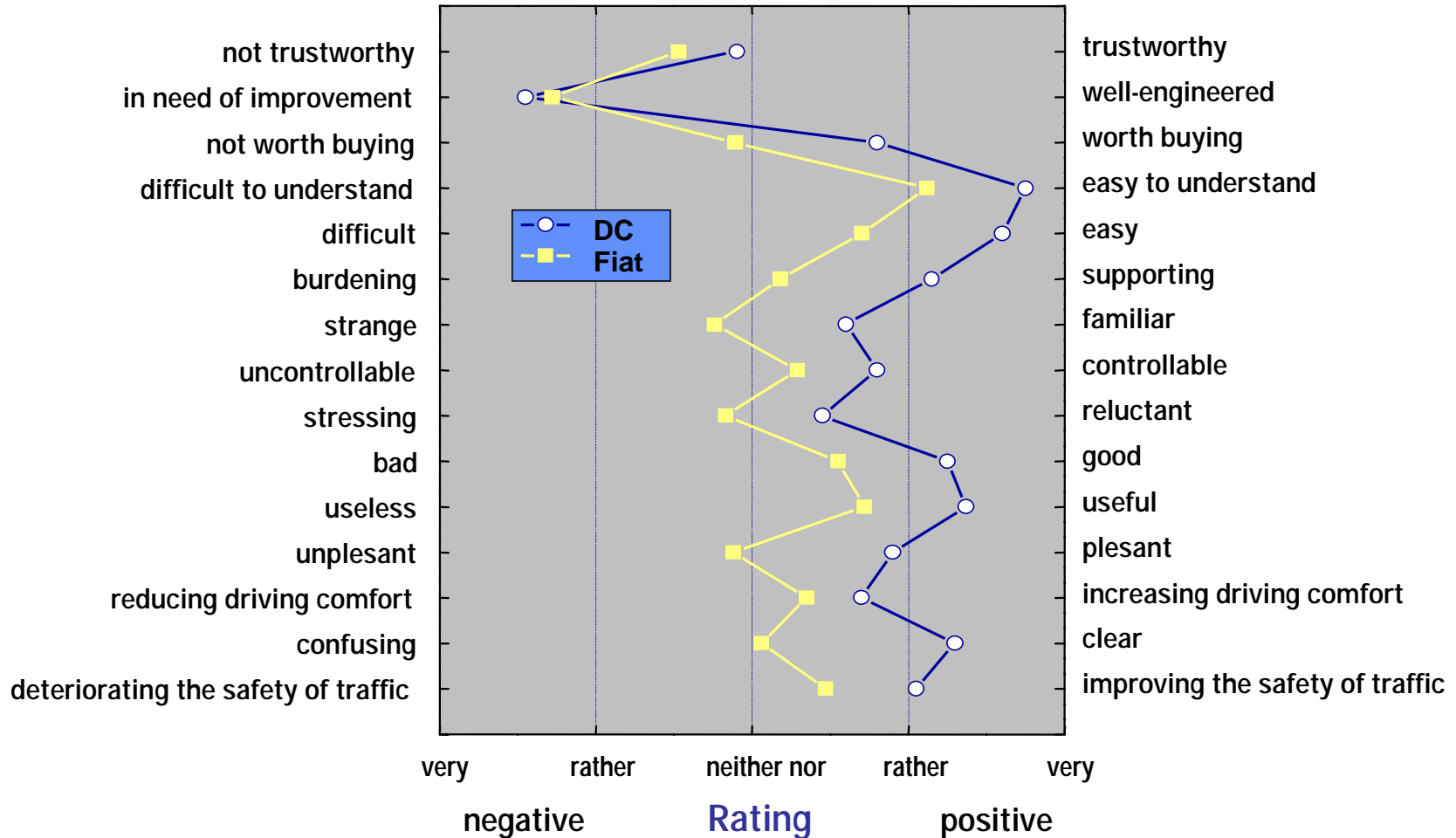
## Post-Questionnaire

- assessment of the system: cognitive, emotional, motivational level, generally, outlook



# PROTECTOR: Results - User Acceptance (source: TÜV)

## I find the PROTECTOR-System ...



- PROTECTOR represented the **first large-scale effort worldwide** to deal with the important problem of sensor-based vulnerable road user (i.e. pedestrian) protection.
- The three sensor technologies considered (24 GHz radar, laser scanner, video) showed their suitability for **obstacle detection**. Only the DaimlerChrysler video system demonstrated its ability for **pedestrian classification**.
- However, for a reasonably high pedestrian classification rate, **classification precision** is still (too) low. Also, in actual warning situations, warning needs to come earlier. Finally, further work is necessary regarding the **risk assessment** and **control/warning strategy**.
- The user **tolerance of false alarms** appears quite low. A **simply warning strategy** (e.g. DC demonstrator: only acoustic, only warning) was better received than the elaborate ones (e.g. two warning-levels).
- PROTECTOR-like driver assistance systems aimed to prevent accidents with vulnerable road users were rated **highly attractive** by users in field tests.
- PROTECTOR introduced a **test methodology** for environmental sensor-based pedestrian protection, usable as **point of reference** for future developments.

**Acronym:** SAVE-U



**Full Title:** Sensors and system Architecture for Vulnerable road User protection

**Duration:** March 2002 - February 2005

**Partners:** Faurecia, VW, DC, SiemensVDO, CEA and MIRA

**Budget:** 7.9 M EUR, of which 1.5 M EUR for DC (7.5 person years)

**Scope:** Vulnerable road user protection (pedestrian) using sensor fusion:  
mono color video & mono FIR & 24 GHz radar.  
Protection by driver warning and/or vehicle braking.

**Demonstrators:**

- VW passenger car
- DC passenger car (includes DC stereo vision system for comparison)

**Web Site:** [www.save-u.org](http://www.save-u.org)



# Comparing the EU Projects PROTECTOR and SAVE-U

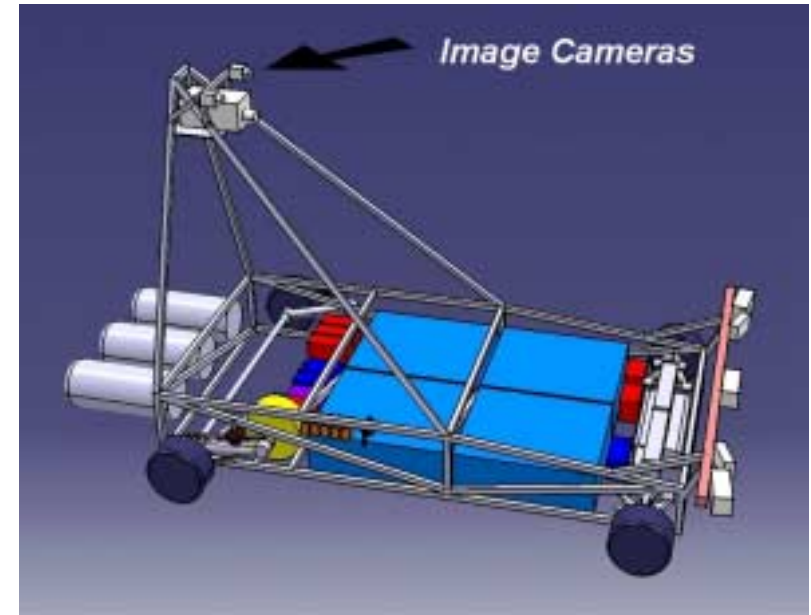
	PROTECTOR (2000-March 2003)	SAVE-U (March 2002 – Feb 2005)
Objective	Protecting Vulnerable Road Users	Protecting Vulnerable Road Users
Safety Concept	Driver Warning	Driver warning, <a href="#">vehicle braking</a>
Sensors	Stereo vision, laser scanner, 24 Ghz radar	<a href="#">mono color video/FIR + 24 GHz radar</a> (stereo vision for comparison)
Sensor Fusion	No	<a href="#">Yes</a>
Traffic Scenario	Urban, driving straight *	Urban, driving straight
Coverage Area	10-25m in front, 2.7-4m lateral *	<a href="#">5-25m in front, 1.4-4m lateral</a>
Environment	Moderate to good visibility, daytime	Moderate to good visibility, day- and <a href="#">nighttime</a>
Vehicle Speed	Up to 30 km/h *	Up to <a href="#">40 km/h</a>
Processing Speed	4 – 15 Hz *	<a href="#">5 – 15 Hz</a>
Detection Perf. (urban driving)	99% trajectory-based *	99% trajectory-based *
Classification Perf. (urban driving)	rate: 45 - 69%, precision: 10 -19% trajectory-based *	<a href="#">rate: 70 - 90%, precision: 60 – 80%</a> trajectory-based

(\*) DaimlerChrysler stereo vision system only

SAVE-U entries reflect planned not actual performance.



- Many runs with **real pedestrians** (incl. weather/time-of-day condition)
- "Vehicle" Speed 40 km/h up to 5m in front of pedestrian
- Braking up to 1g, safety provided by placing sensors on test rig attached to cables.
- First data collection starts April/May 2004
- Tests performed by MIRA (UK)



- Pedestrian protection is increasingly relevant in view of [legislative initiatives](#).
- Customers are not likely to pay for a separate pedestrian protection system. Pedestrian-specific sensing capabilities can however provide considerable [add-on value](#) to safety/driver-assistance systems.
- There has been [swift progress](#) on video-based pedestrian recognition over the last 2-3 years. We are currently working with large, realistic datasets from urban traffic and produce both „hard“, quantitative sensor performance data and subjective user feedback. System specs were derived taking into account accident analysis.
- [More research](#) is needed before these systems can be placed at the hands of ordinary vehicle drivers.

## Survey Article on Pedestrian Sensing:

- D. M. Gavrila. „Sensor-based Pedestrian Protection“ *IEEE Intelligent Systems*, vol.16, nr.6, pp.77-81, 2001.

## DaimlerChrysler Video-based Pedestrian System:

- D. M. Gavrila and J. Giebel. „Shape-based Pedestrian Detection and Tracking“ *IEEE Symposium on Intelligent Vehicles*, Paris, France, 2002.

## PROTECTOR EU Project (2000-2003)

- R. Cicilloni, S. Deutsche, K.M. Oltersdorf and D.M. Gavrila. „Results of Vulnerable Road User Protection System in PROTECTOR“. ITS World Congress, Madrid, 2003.

## SAVE-U EU Project

- [www.save-u.org](http://www.save-u.org)

- **PROTECTOR Deliverable 5: Validation Results**

User acceptance from field trials: cognitive, emotional, motivational level

- **SAVE-U Deliverable 1-A: Vulnerable Road User Scenario Analysis SAVE-U**

Detailed Pedestrian Accident Statistics (D, F, EU, USA) up to 2001:  
by Age, Location, Collision Opponent, Initial/Impact Speed, Weather, Accident Type, etc.

- **SAVE-U Deliverable 6: Strategies in Terms of Vulnerable Road User Protection**

Active Hood/Bumper, Automatic Braking, Driver Warning, Night Vision, etc.

- Survey publications, patents, internet sites
- Discussion: classification of various actuator concepts, requirements for sensors

- **1<sup>st</sup> Annual SAVE-U Project Report, 2002 - 2003**

Snapshot of March 2003 project status, by Work Package