*Environmental Perception & Cooperative Driving*

# Developments in Advanced Driver Assistance

**TNO | Knowledge for business**

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Bits & Chips Embedded Systems 2010

November 11, 2010

# Outline

- Introduction
  - Trends in Advanced Driver Assistance
- Collision mitigation & avoidance
  - Probabilistic Risk Estimation for Vulnerable Road Users
- Cooperative Driving
  - Cooperative Adaptive Cruise Control
- Conclusions

# Advanced Driver Assistance (ADA) trends

- Advanced Driver Assistance (ADA) systems
  - "systems that support the driver in his driving task, primarily based on information regarding the environmental traffic situation"
- Main trend:

controllability: autonomous driving

- Cooperative Driving results in[2]:
  - 50% less traffic congestion
  - 8% less traffic accidents

- VRU safety[1]:
  - 43% road fatalities are pedestrians
  - 5% cyclists

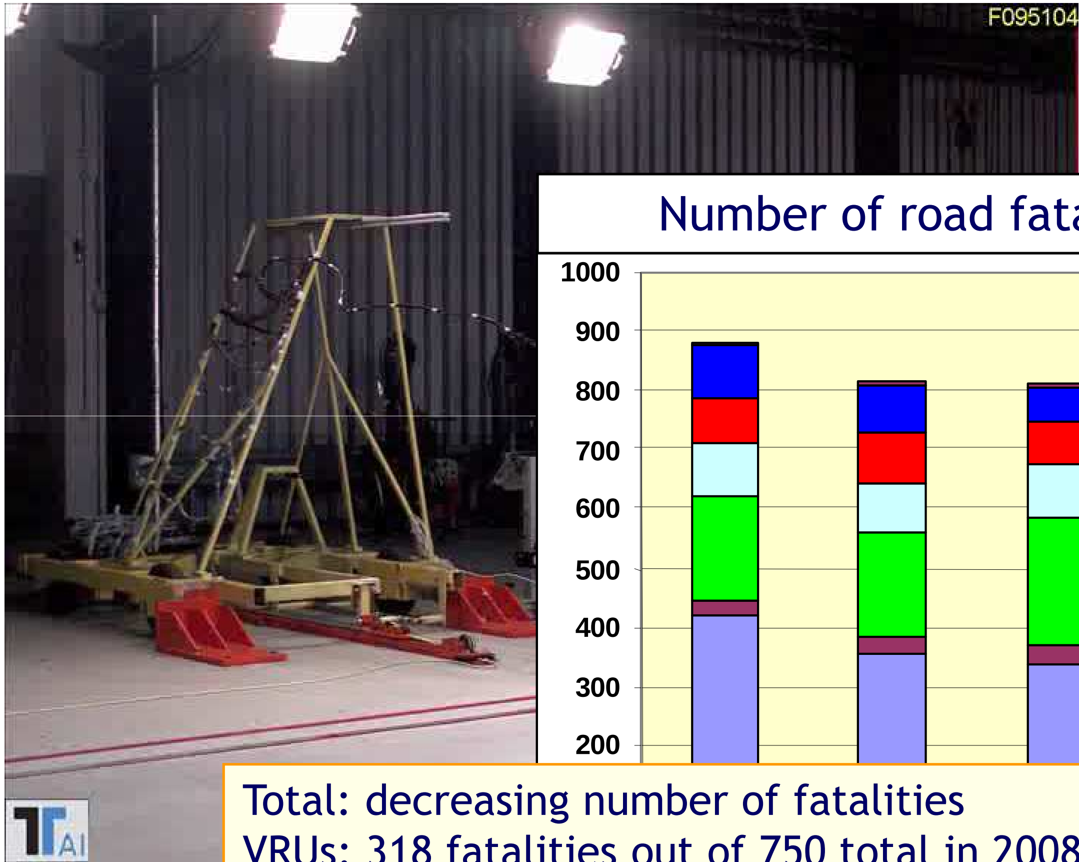
mobility: cooperative driving

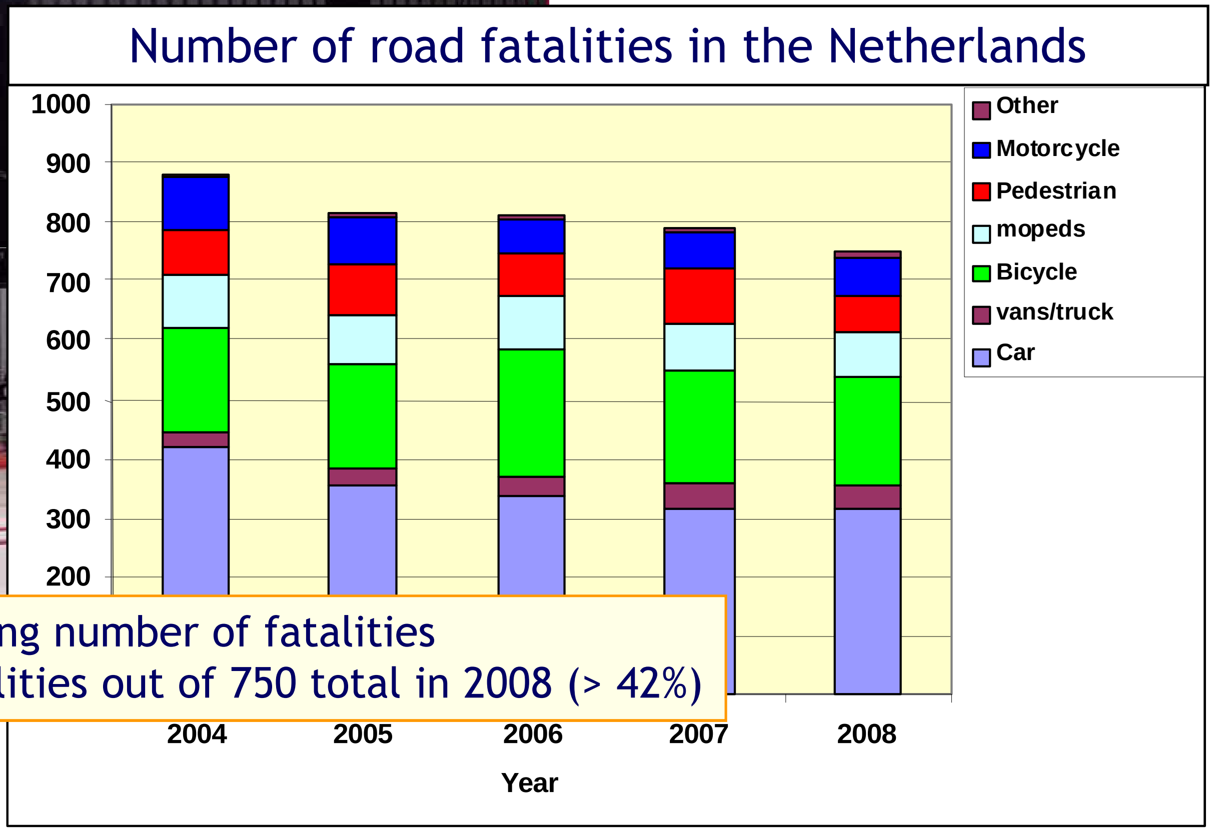
safety: car-to-car collisions → vulnerable road users


comfort: cruise control, advanced cruise control

[1] ETSC PIN annual report 2009
[2] TNO report 2008-D-R0996/A "Smarter and better – the benefits of intelligent traffic"

# ADA trend 1: Vulnerable Road Users




Total: decreasing number of fatalities
VRUs: 318 fatalities out of 750 total in 2008 (> 42%)

Rijkswaterstaat, *Kerncijfers Verkeersveiligheid*, www.rijkswaterstaat.nl/dvs, 2009

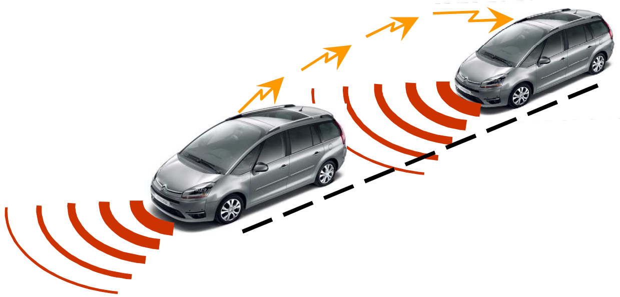
# ADA trend 2: Cooperative Driving

- A growing need for mobility, individuality, freedom
- Expected growth in mobility 20 – 30% in the coming decade (in the Netherlands) ⇒ ‘vehicle loss hours’ will double

- Environmental awareness and climate change will support the demand for clever solutions (instead of more roads)

⇒ Cooperative Driving

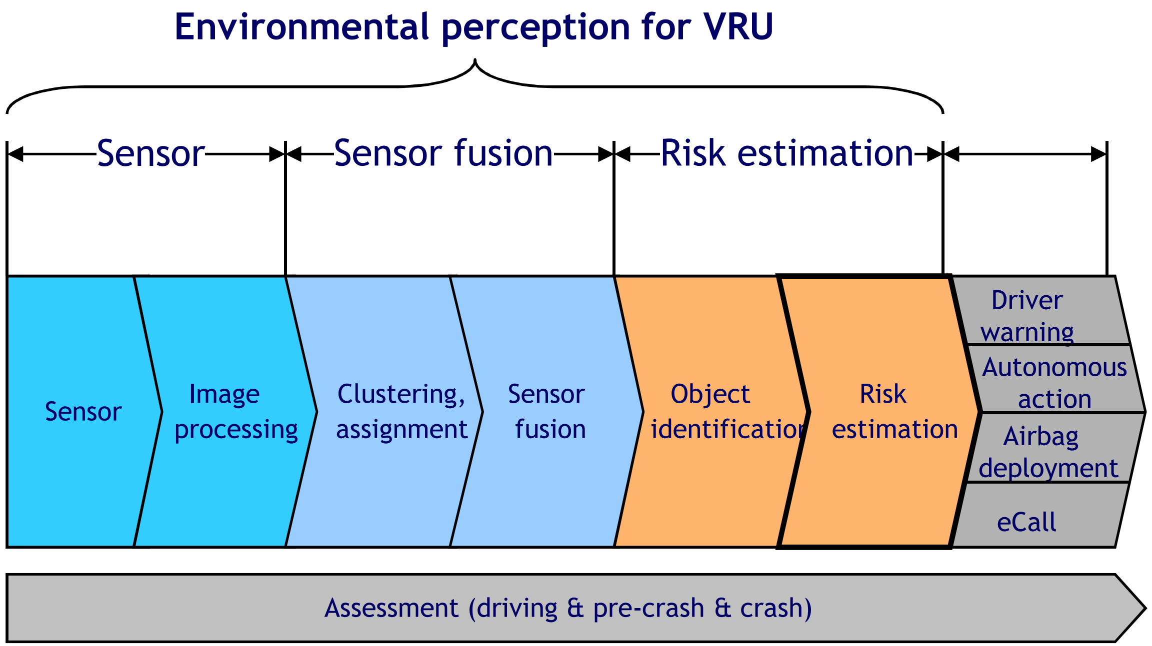
  - Influencing individual vehicles, either through advisory or autonomous actions, so as to optimize the collective behavior with respect to:
    - Throughput (highways + urban roads)
    - Safety (also affects throughput)
    - Emission/fuel consumption (trucks)



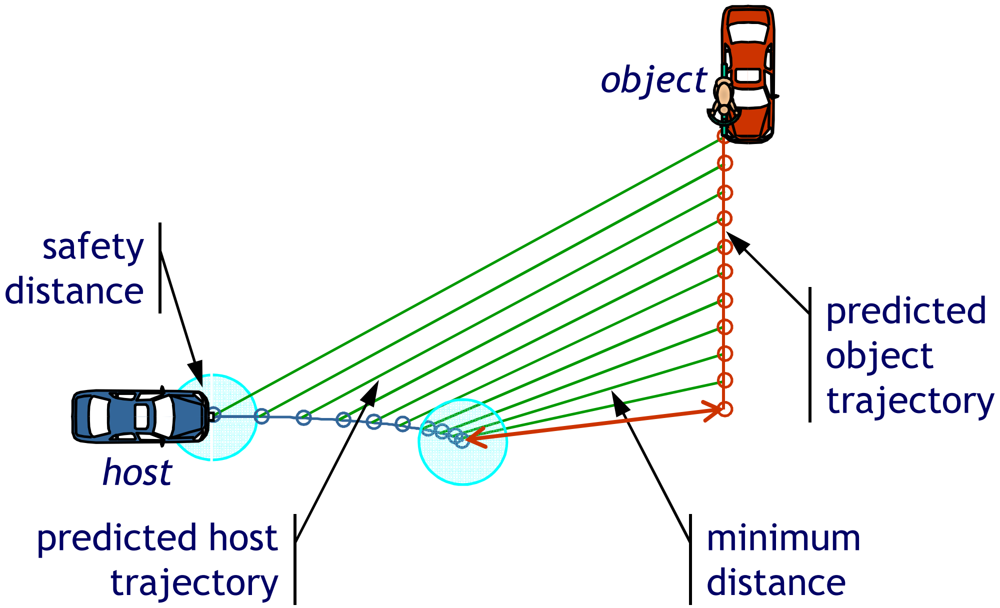
- Main enabler: wireless communication

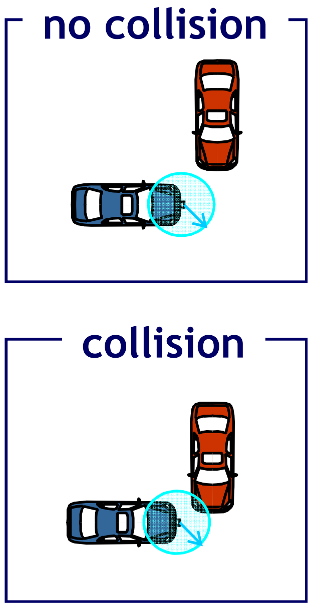
# Risk estimation for VRUs

- Injury reduction
  - Driver warning
  - Autonomous braking
  - Airbag deployment to reduce impact



# Vehicle risk estimation



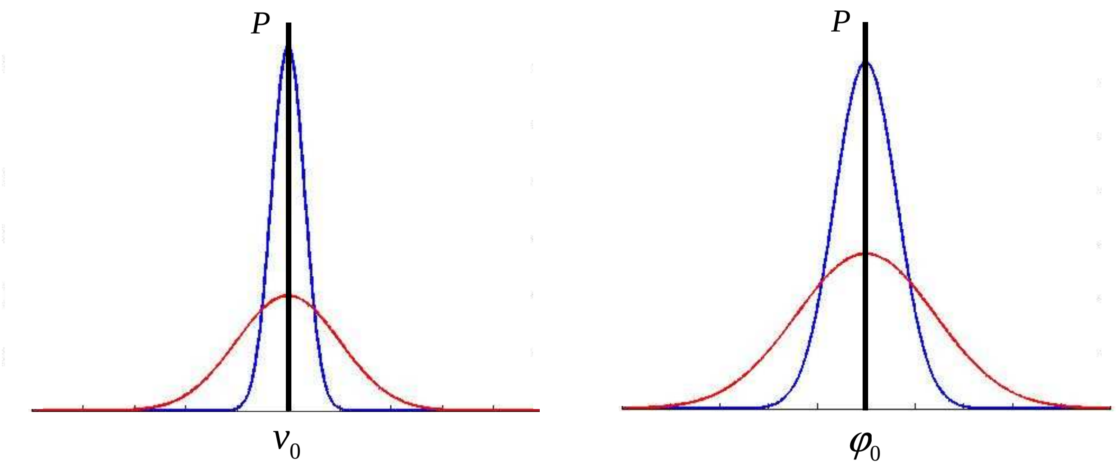




- Predict trajectories of detected objects (vehicles) and host vehicle across a predicted time-horizon
- Quantify optimal trajectory by use of a cost function
  - Collision-free -> keep safe distance to obstructing objects
  - Feasible trajectory -> low accelerations
- Minimize the cost function by choosing optimal host vehicle trajectory

# Risk estimation for VRUs: main principle

- VRUs behave rather non-deterministic
- Probabilistic approach is proposed to cover the resulting uncertainty in the path prediction of VRUs

**Probability Density Functions (PDF)**




**Probabilistic Risk Estimation**

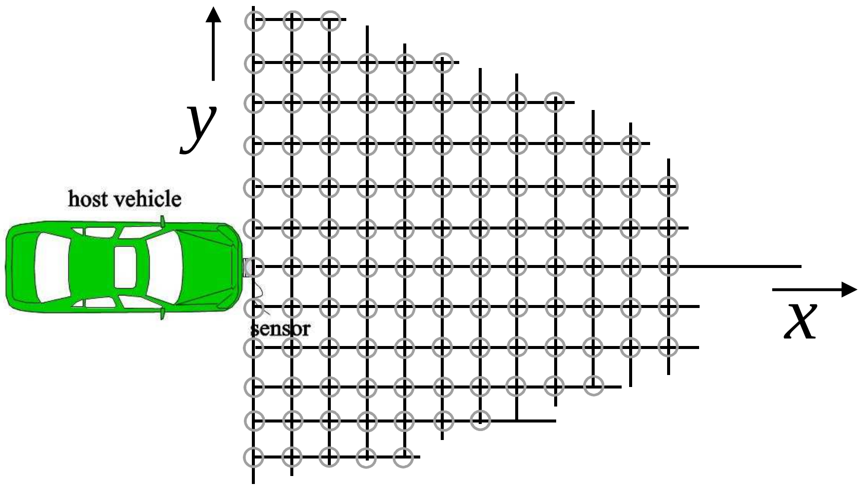
- Assumption: object classification is known to choose the correct PDF

# Risk estimation for VRUs: implementation

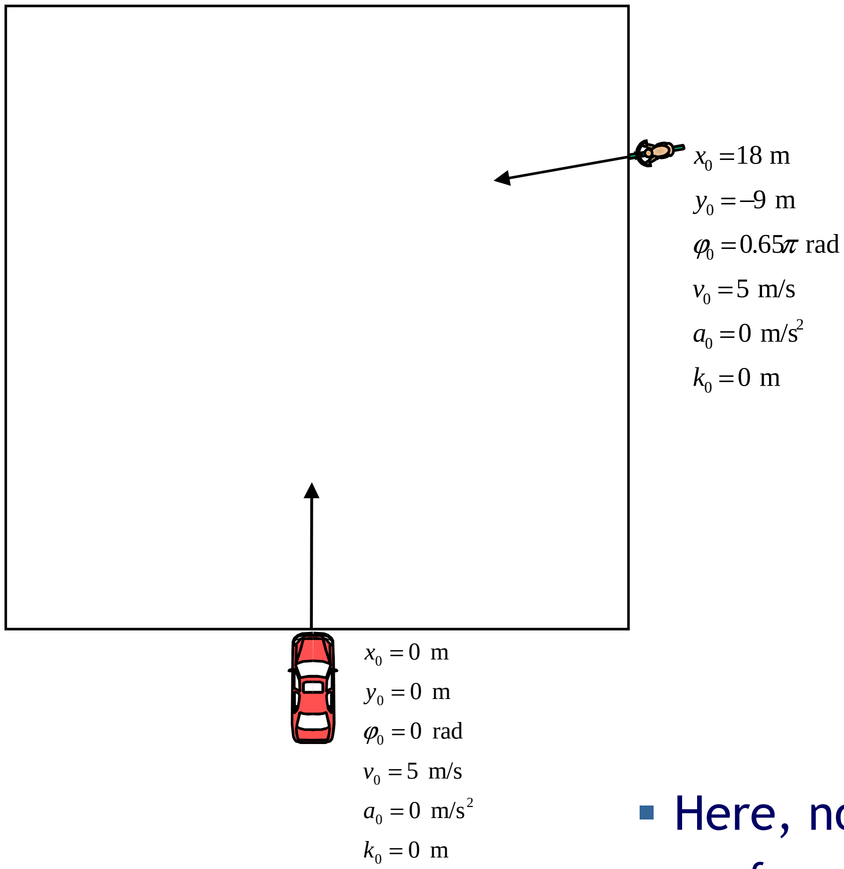
1. At time $t = t_0$ the position, orientation, velocity, (rotational velocity and acceleration) are known of the detected object(s) and own vehicle

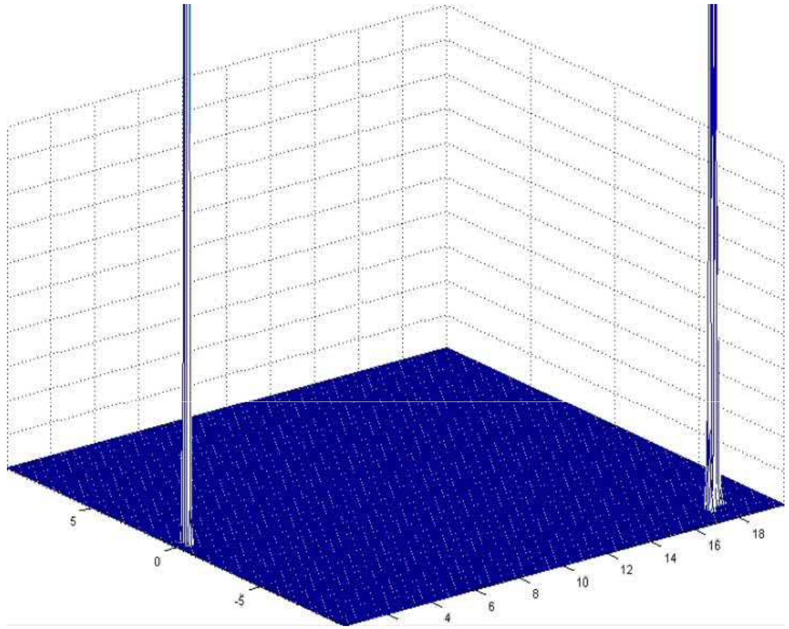
2. Determine future position of the object over a certain time horizon

3. Determine probability at a specified position $(x,y)$ in time over a large range of possible positions



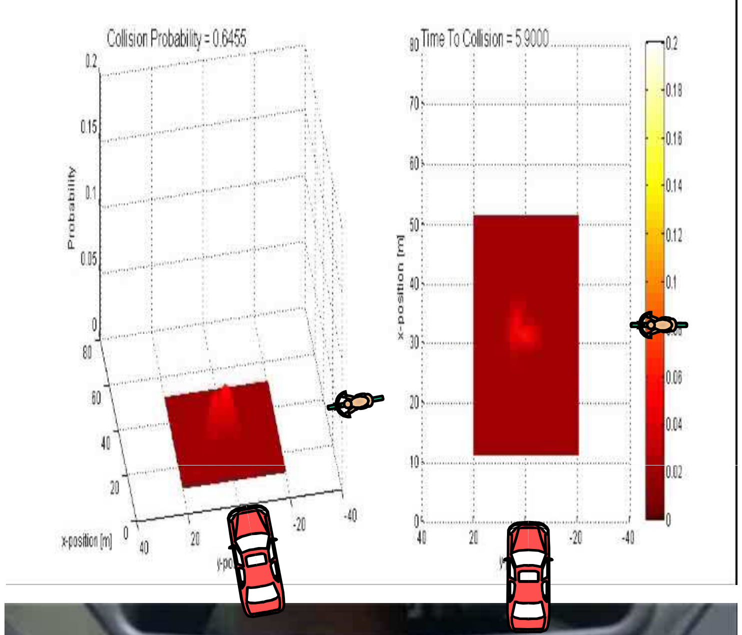
# Risk estimation for VRUs: simulation

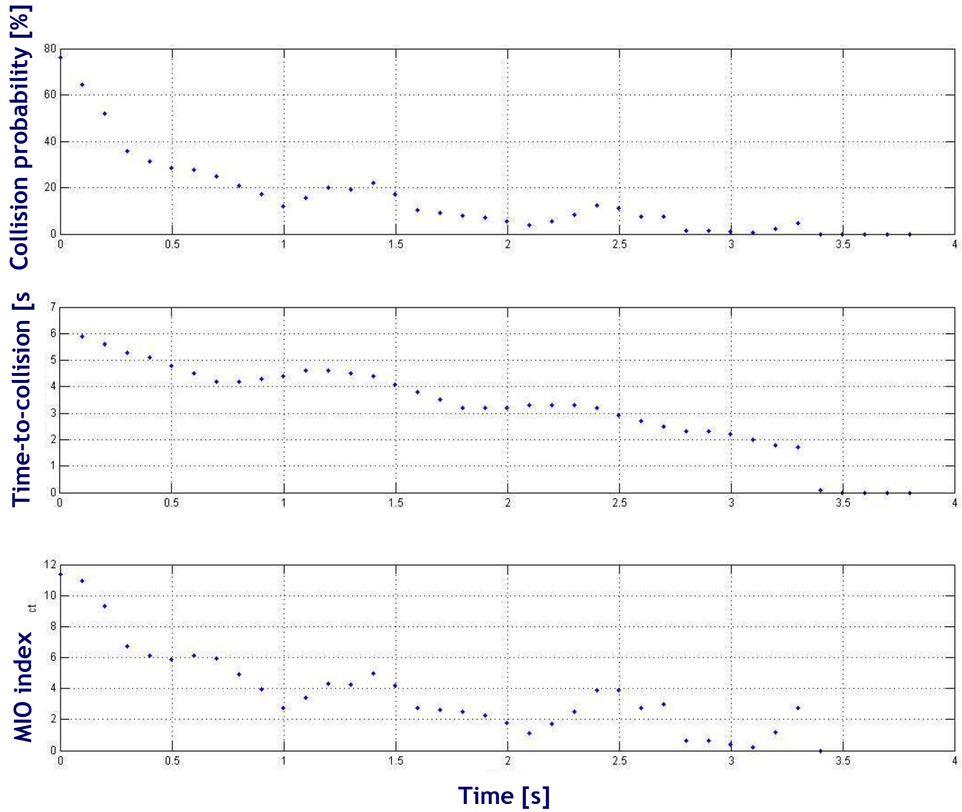



- Here, normal distributions are chosen for:
  - forward velocity
  - heading

# Risk estimation for VRUs: experiments




$$\text{MIO index} = \frac{\text{collision probability}}{\text{time - to - collision}}$$

# Risk estimation for VRUs: summary

- Probabilistic Risk Estimation (PRE) provides an estimation of the collision probability in the presence of large uncertainties with respect to future object behavior (such as with VRUs)

- Numerically intensive ⇒ puts “high” demand on computation power

- Modular, generic approach, serving multiple ADAS applications
  - object detection & classification
  - prediction & risk estimation

⇒ HW/SW must be interoperable

- Safety-critical application ⇒ high degree of reliability of HW/SW

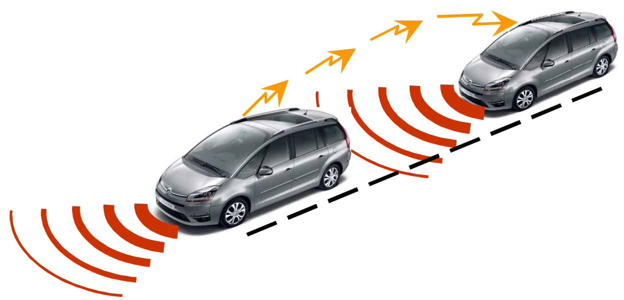
- Liability issue: will the driver remain responsible?

# Cooperative Driving

- Two types of systems, roughly
  - Warning/advisory systems → not time-critical → event-triggered
  - Automatic systems → time-critical → time-triggered → closed loop control

⇒ Cooperative Adaptive Cruise Control (CACC)

- Increase road capacity by decreasing the time gap between vehicles
- Mitigate resulting(!) shockwaves
- Decrease fuel consumption (trucks)
- Automatic control of headway distance using wireless communications

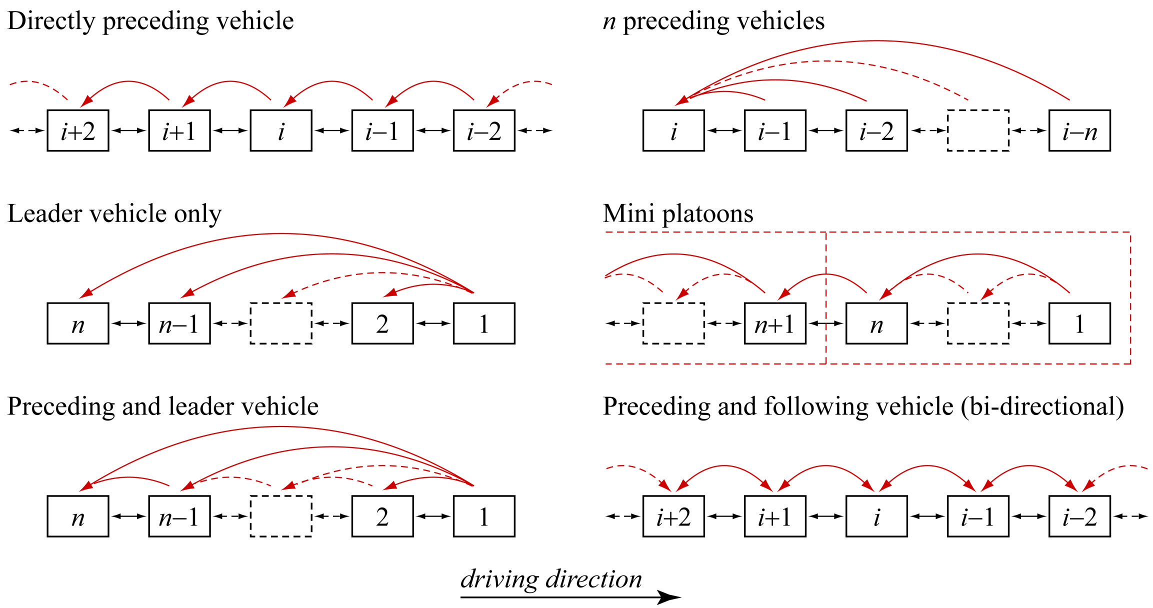


- Worldwide activities
  1. Control system development, including fail safety
  2. Environmental awareness (target tracking)
  3. Scaling issues related to wireless communication (fail safety)
  4. Enhance awareness from stakeholders (government, public)

# CACC control objectives (qualitatively)

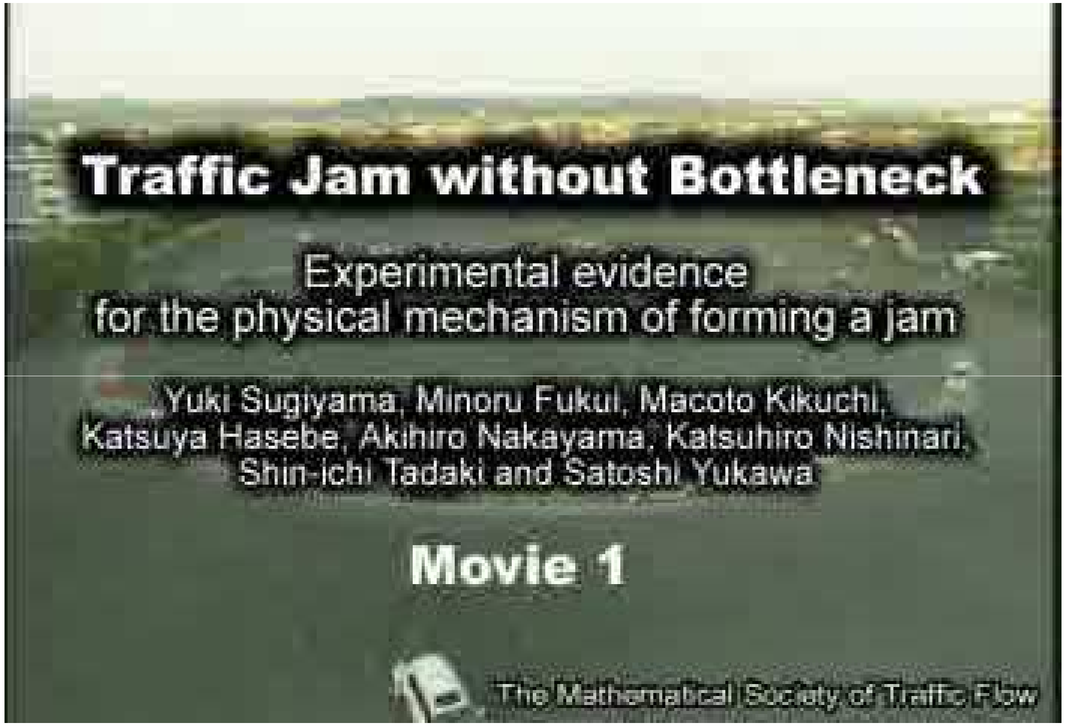
- Stability & performance of individual vehicle
  - Relatively low bandwidth in view of comfort (same as ACC)
- Spacing policy: headway as small as possible
  - Taking safety into account as a constraint
- Attenuation of oscillations in upstream direction: string stability
  - Note: it is still not clear wether String Stability is a true stability criterion, or a performance objective
- Reliability in the presence of sensor faults: fault tolerance & graceful degradation
  - Robust against wireless comunication impairments
  - Robust against radar/lidar/camera errors (false detections, missed detections)

# CACC communication structures




- Unidirectional communication with directly preceding vehicle
  - Least demanding for communication
  - No designated platoon leader
- Bidirectional communication: preceding and following vehicle
  - Platoon coherence
  - Seems very suitable for truck platoons (decreased aerodynamic drag!!)

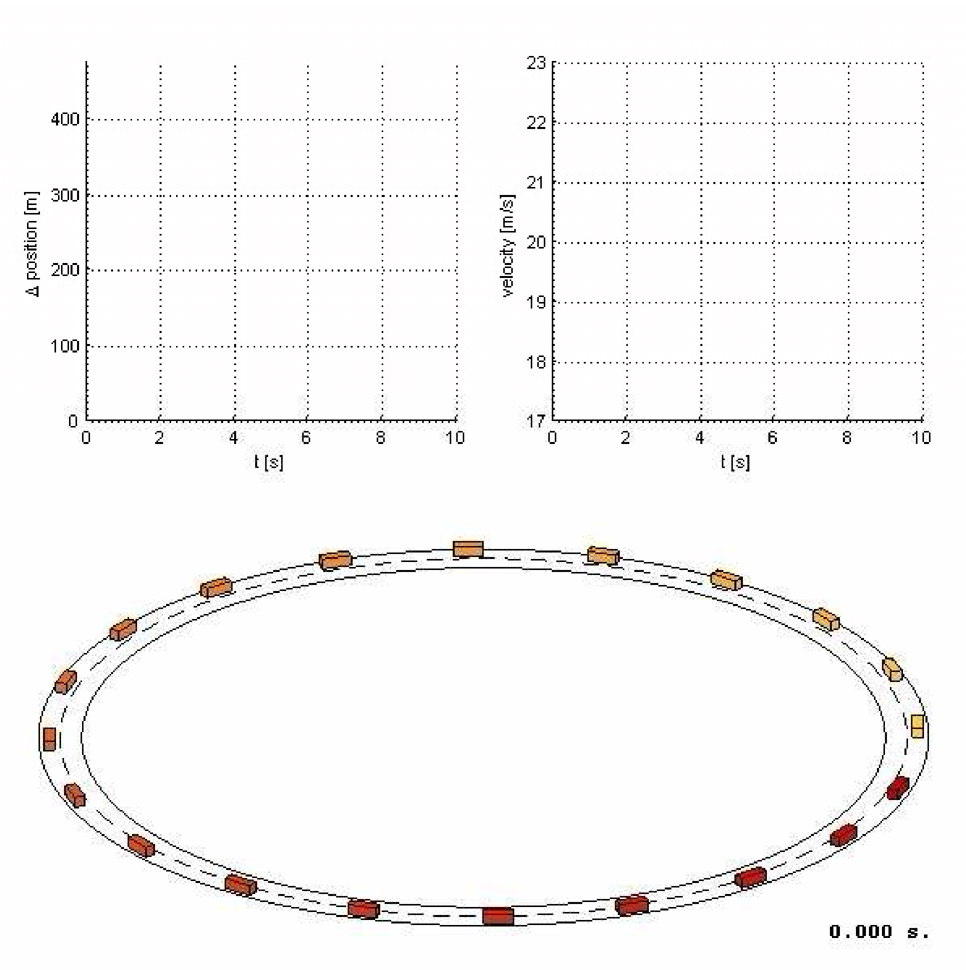
# Human driving behavior




- Sugiyama, Y.; Fukui, M.; Kikuchi, M.; Hasebe, K.; Nakayama, A.; Nishinari, K.; Tadaki, S. & Yukawa, S., Traffic Jams without Bottlenecks - Experimental Evidence for the Physical Mechanism of the Formation of a Jam. New Journal of Physics, 2008, 10 (033001), 7

# ACC

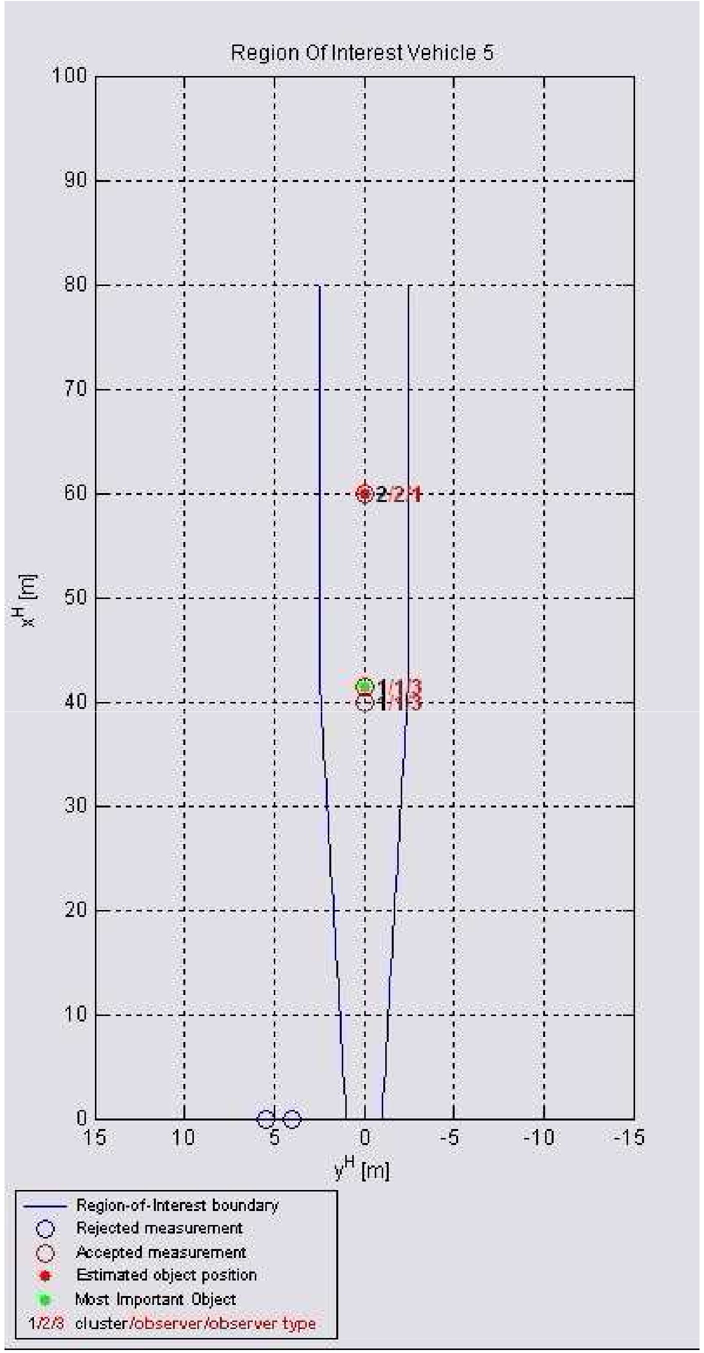
- Infinite string
- ACC, with time headway $h = 0.5$ s
- Initial velocity 72 km/h
- Initial condition error of one vehicle of 2 m
- String unstable ⇒ with linear controller, a collision occurs



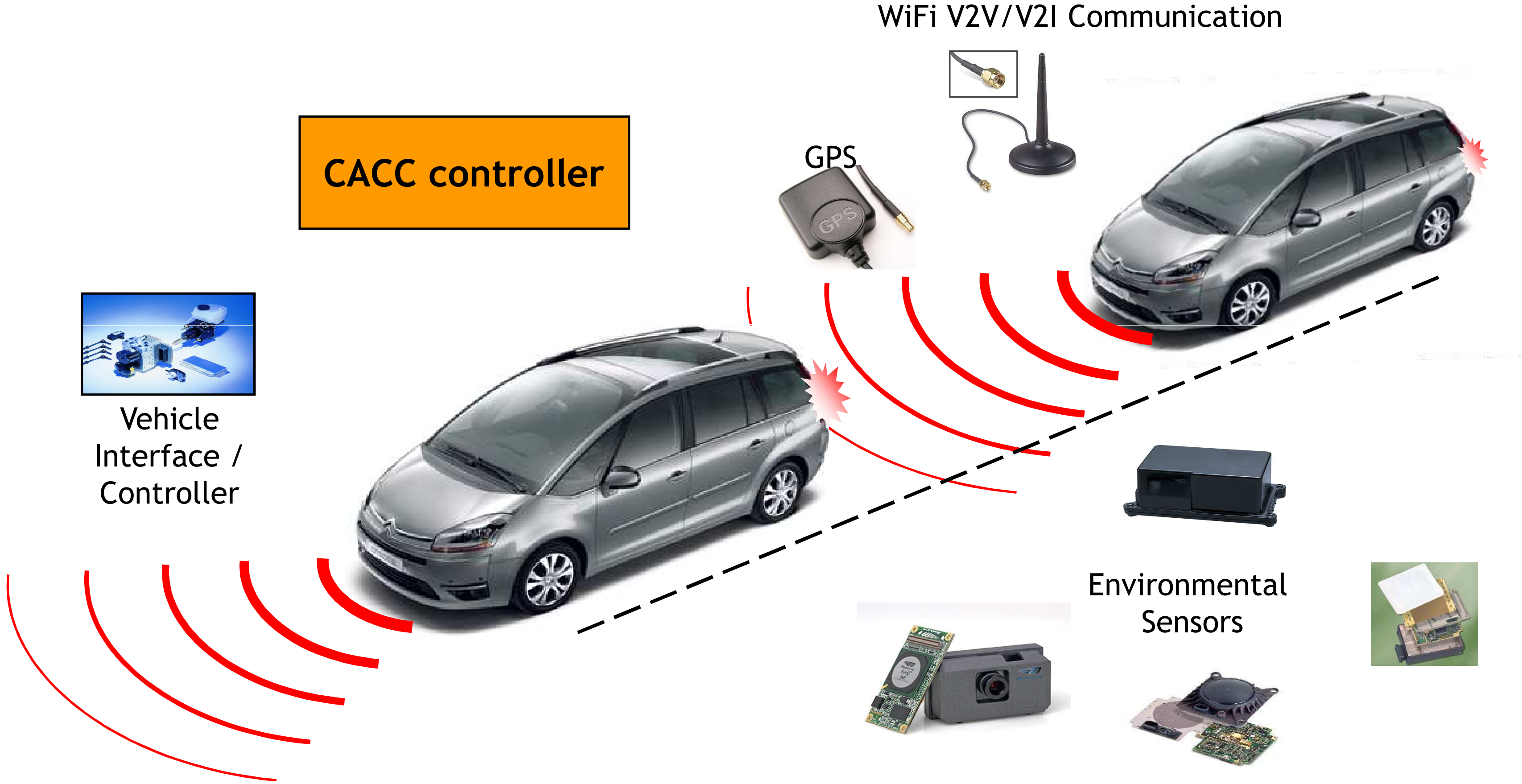
# Object tracking for CACC

- Object Tracking characteristics
  - Determine relevant target vehicles based on multiple sensors, s.a. wireless comm. (802.11p) and radar
  - Packet-loss & inaccuracy of communicated GPS data biggest challenge

- Object Tracking steps at a glance
  - Pre-processing
  - Feature filtering (ROI)
  - Data clustering
  - Sensor fusion
  - Object classification (MIO)



# Control design: hardware



# First experimental results

# CACC summary

- CACC allows for very small headway times while maintaining string stability ⇒ increases road capacity/decreases fuel consumption
- Design focusing on implementation is feasible
  - CACC can be regarded as add-on to ACC
  - Standardization in wireless communicatiosn well under way (802.11p)
- Numerically intensive ⇒ puts "high" demand on computational power
- Object tracking is a generic component (also used in VRU safety)

⇒ HW/SW must be interoperable

- Safety-critical application ⇒ high degree of reliability of HW/SW
- Based on wireless comm. ⇒ high degree of security

# Conclusions

- Advanced Driver Assistance:
  - Increased focus on VRU safety
  - Increased focus on Cooperative Driving through wireless communications

- Both types, although very different by nature, rely to a large extend on detection, estimation & classification of road users

- Both types are time- & safety-critical and even automatic

⇒ Software & hardware characteristics:
  - High computational power
  - At the same time high degree of reliability
  - Interoperable