INTRODUCTION TO VEHICLE SAFETY AND CRASHWORTHINESS

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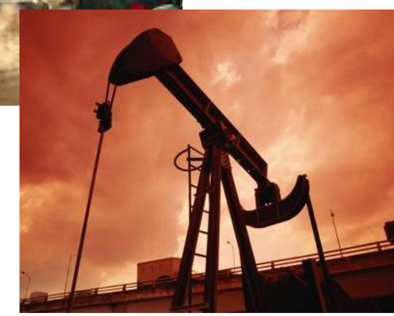
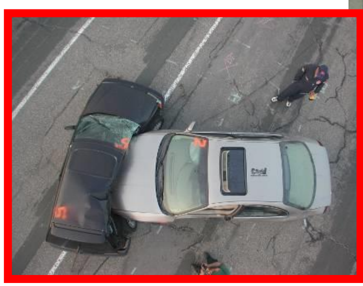
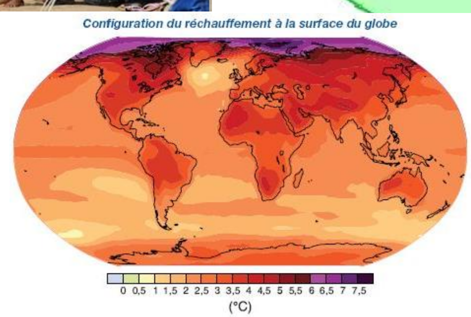
Sustainability in automotive industry







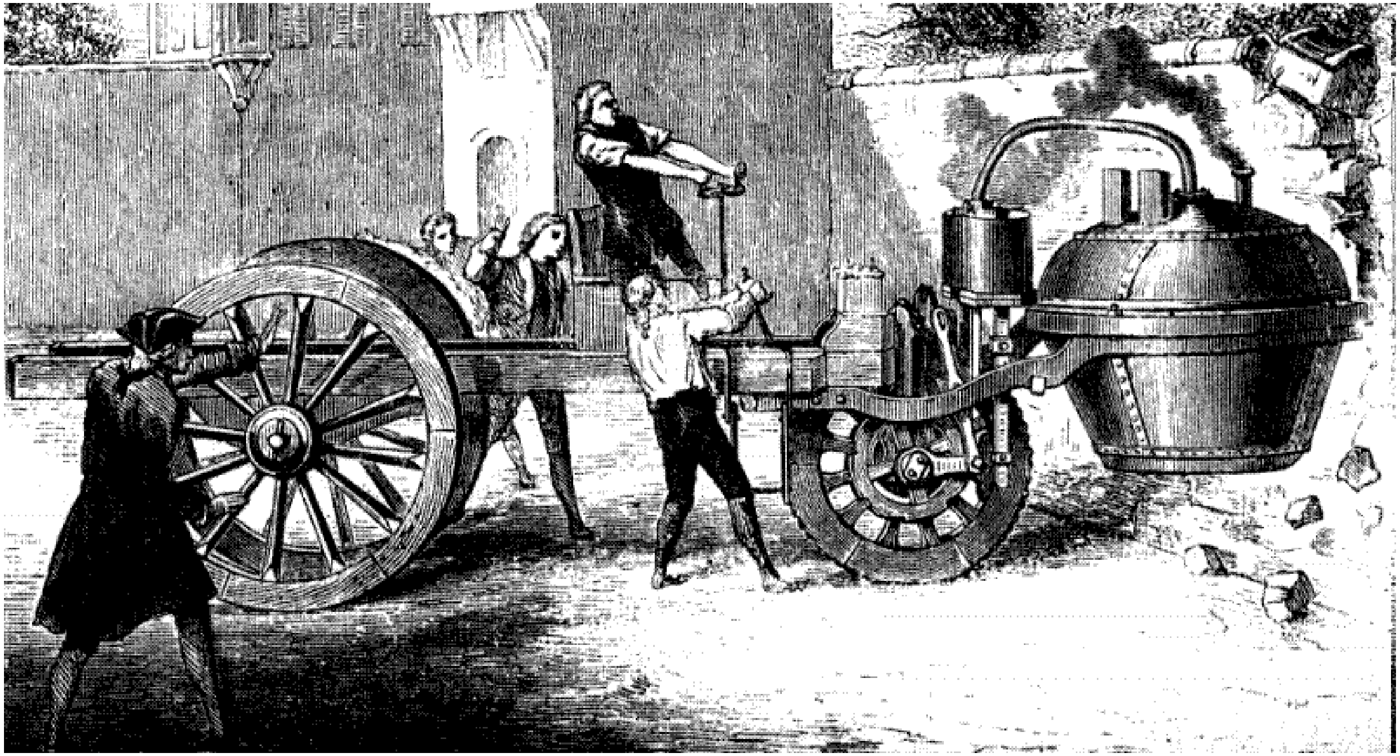
Introduction

- Vehicle safety and more generally road safety is intrinsically a part of a sustainable automotive industry

- Road safety has a considerable impact on society
  - Emotional impact of people who experience the accidents
  - Economical impact of dead or wounded people
    - Cost on health care system
    - Loss on investment on educated young people who are the future of the society and economy

- Road safety must be considered as a high priority constraint of the development of automobile systems and road infrastructures

Introduction



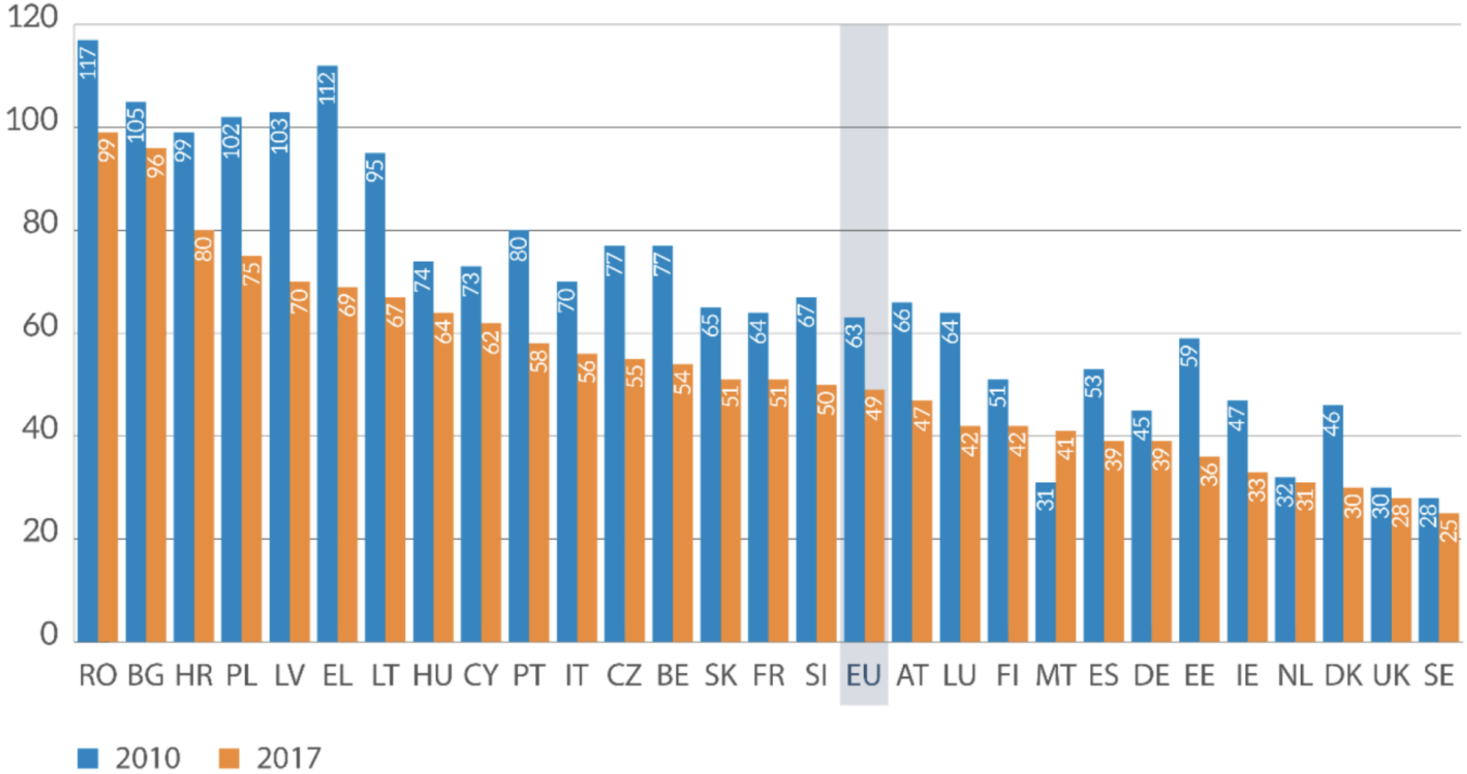
Fardier of Cugnot: First road accident in 1770

Introduction

- Vehicle safety is a societal issue.
  - Worldwide, 1 person dies on the road every minutes
  - The cost of the road accident is estimated to 3% of world GDP, that is about € 1 billion
  - High emotional cost
- From very early, car manufacturers and public operators have paid attention to road accidents and fatalities.
- Different technical and educational solutions have been tailored, but the challenge is still important.
- One major factor: 70 to 90% of the accidents are due to human errors.
- With the weight reduction and fuel consumption the problem becomes even more critical.

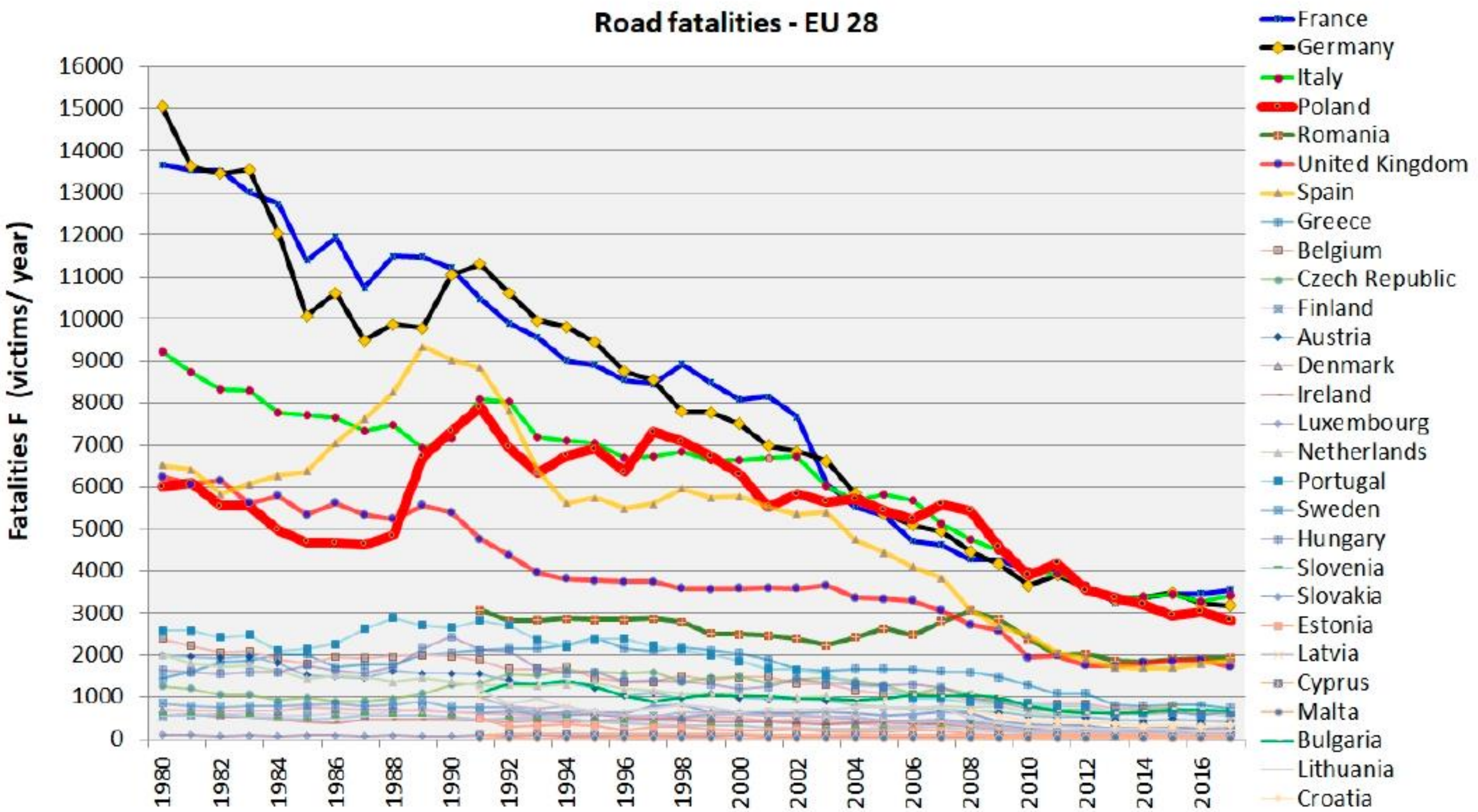
Introduction

Road death per million inhabitants in EU



Source: 2010 data: European Commission's press release, 10 April 2018; 2017 data: European Commission, [Road safefy 2017 – How is your country doing?](), November 2018.

Introduction



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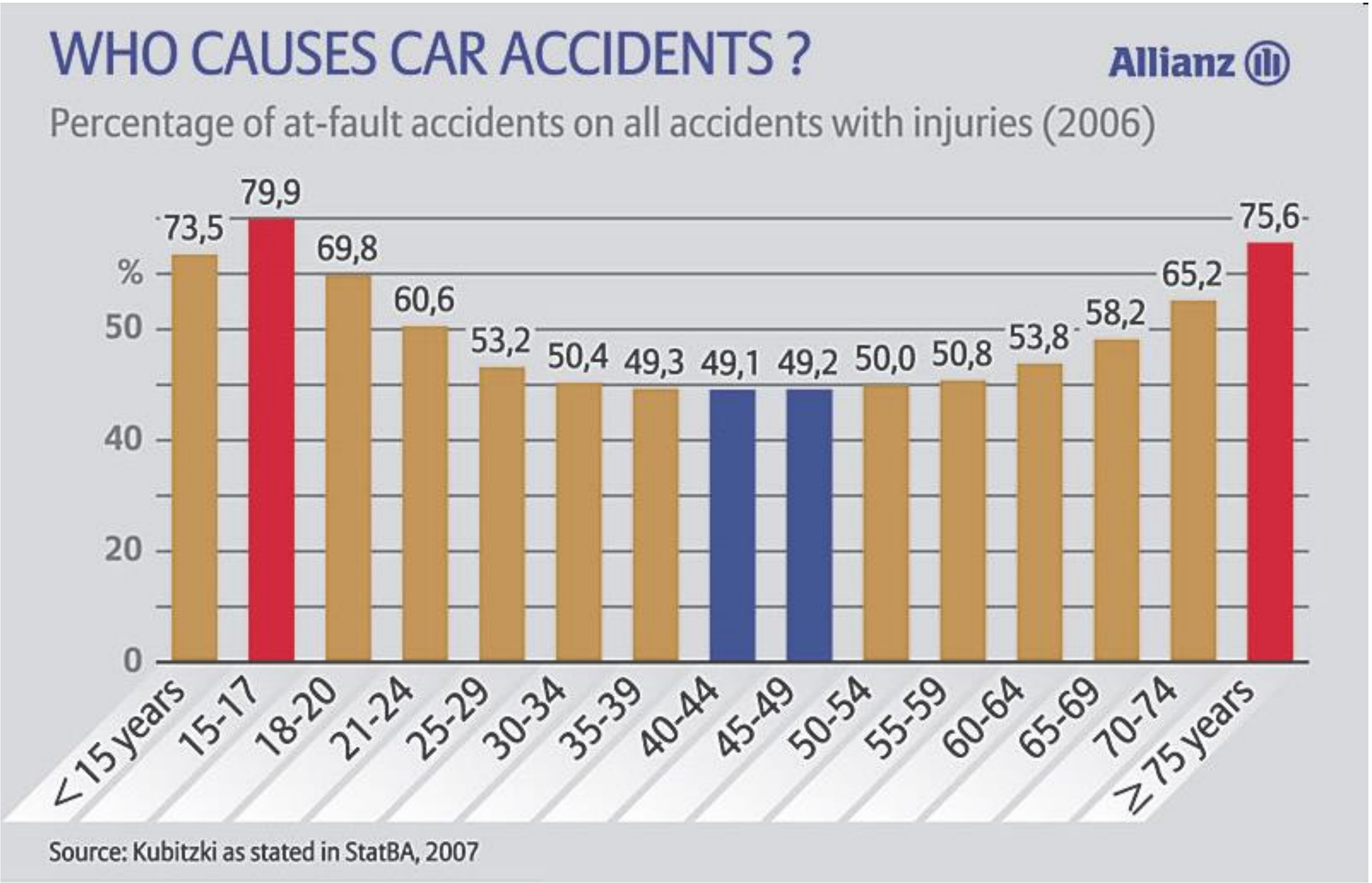
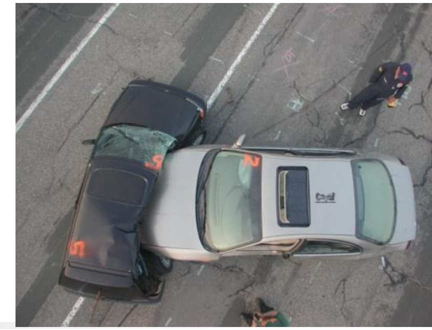




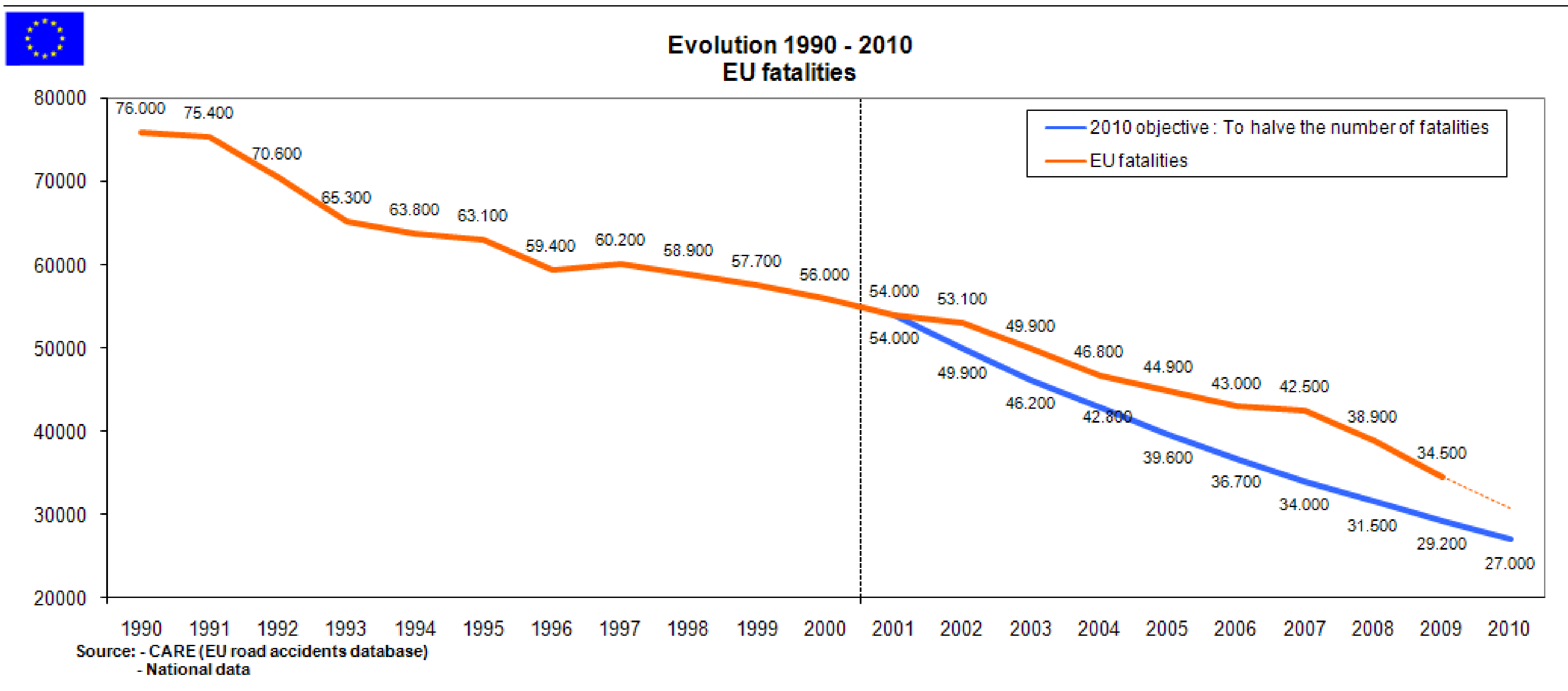
EU White paper

- In 2000 the EU commission stressed an ambitious program in order to reduce the fatalities in roads accidents by a factor 2

- Situation in 2000
  - 41000 fatalities per year in EU
  - Total cost of road accidents: 2% of the GDP
  - Expenses for preventing < 5% of the this cost

- Tools to achieve the target
  - To promote the new technologies
    - Faces, black boxes,
  - To harmonize the penalties
    - Speed limits, alcohols…

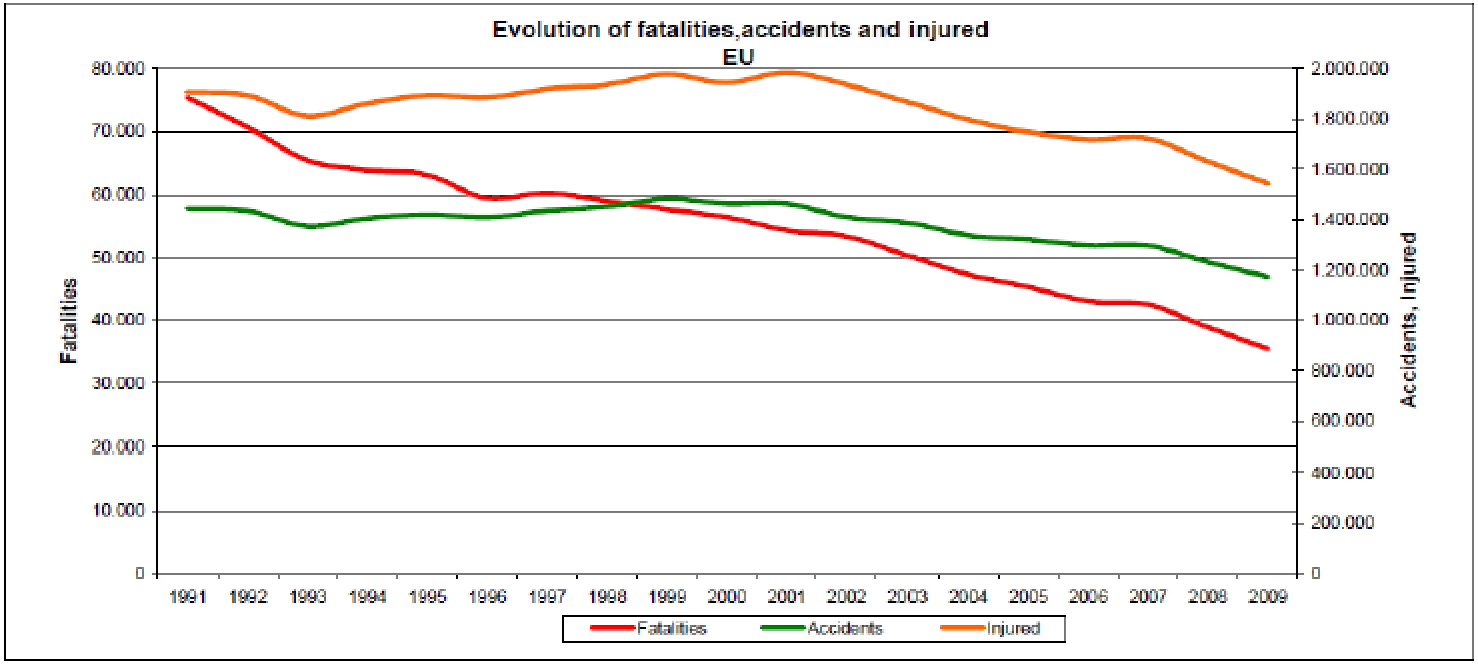
Fatalities in road accidents in EU



Targets for 2030

	Indicator	Guiding objective
Decarbonization	Energy efficiency: urban passenger transport	+80% *
	Energy efficiency: long-distance freight transport	+40% *
	Renewables in the energy pool	Biofuels: 25% Electricity: 5%
Reliability	Reliability of transport schedules	+50% *
	Urban accessibility	Preserve Improve where possible
Safety	Fatalities and severe injuries	-60% *
	Cargo lost to theft and damage	-70% *

Targets for 2030: safety issues



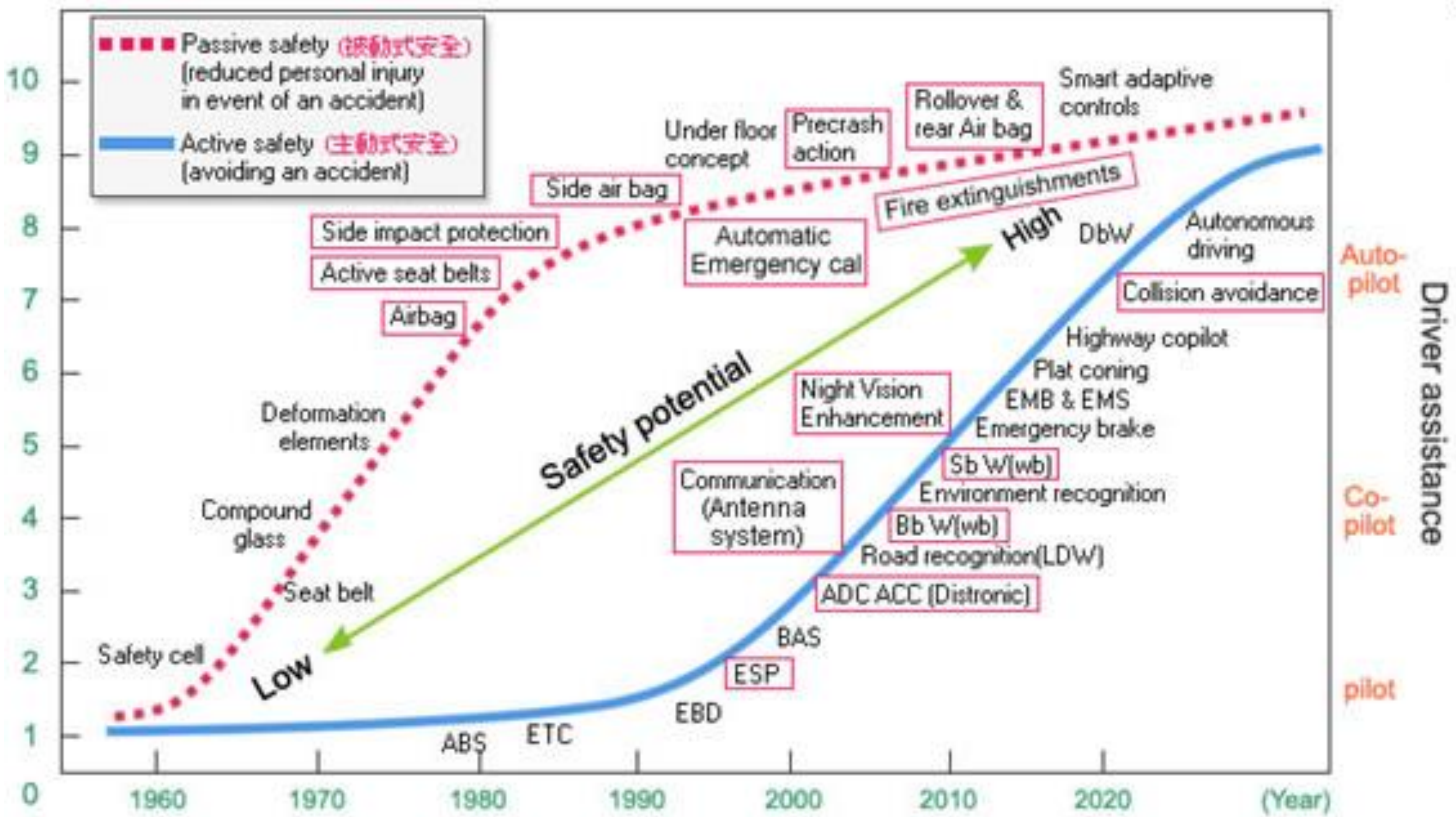
Societal Need	Indicator	Guiding objective for 2030
Safety	Fatalities and Severe Injuries	-60%*
	Cargo lost to theft and damage	-70%*

PART I : PASSIVE SAFETY

PASSIVE AND ACTIVE SAFETY SYSTEMS

- Active safety: all the measures reducing the probability of occurrence of accidents
- Passive safety: Reactive measures that aims at reducing the severity of the injuries in case of crash (when it can not be avoided)
- Educational measures: Safety campaign against speed, driving under alcohol, drugs, etc.

PASSIVE AND ACTIVE SAFETY SYSTEMS

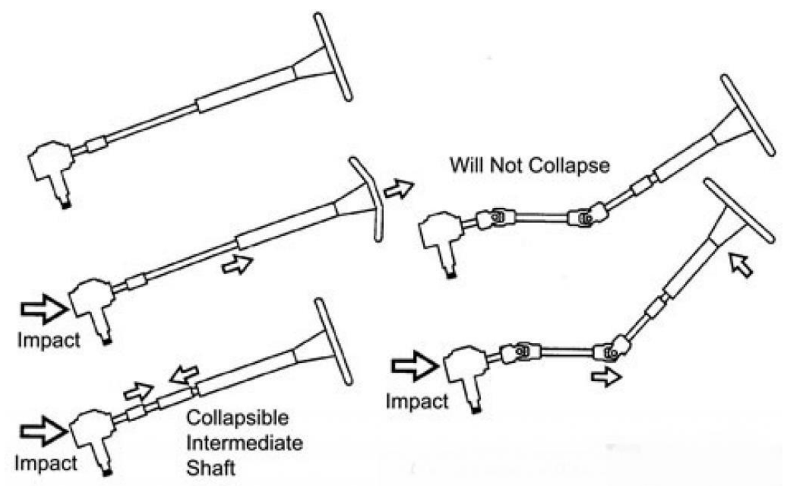


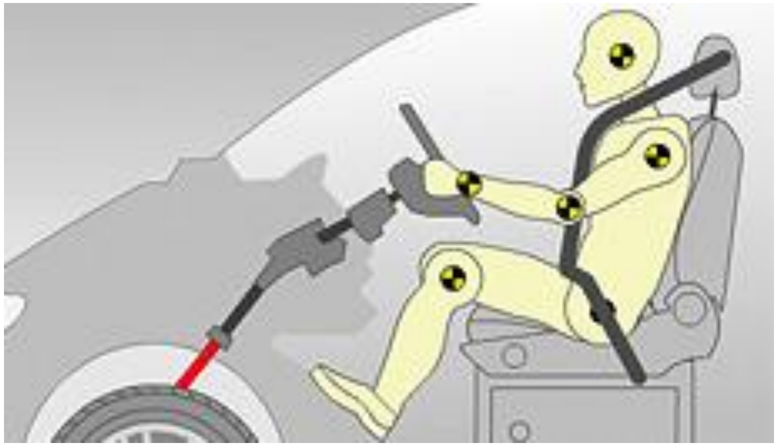
ACTIVE & PASSIVE SAFETY SYSTEMS

Vehicle safety system configuration diagram to be developed

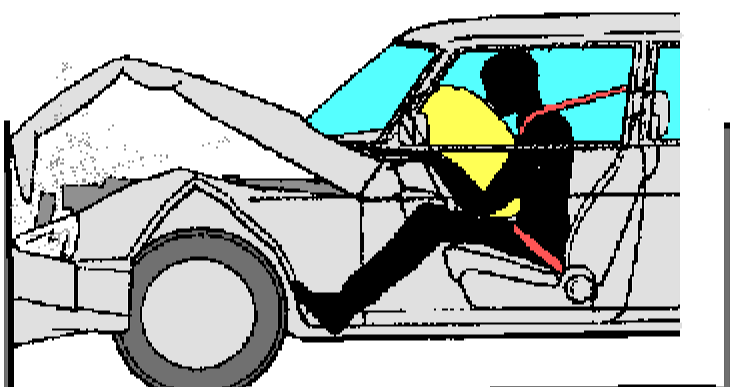
Steering column

- First attempt was the modification of the steering wheel and the steering column not to impact the driver
- In 1950ies, a massive steering wheel with a metal-horn rim connected to a steering column that was a rigid piece. So, in a frontal collision, the driver was effectively at the business end of a battering ram.
- Then, designers shrunk tailfins, engineers developed collapsible steering columns consisting of multiple parts. Rather than shooting toward the driver upon heavy impact, the column's sections compact like a telescope.



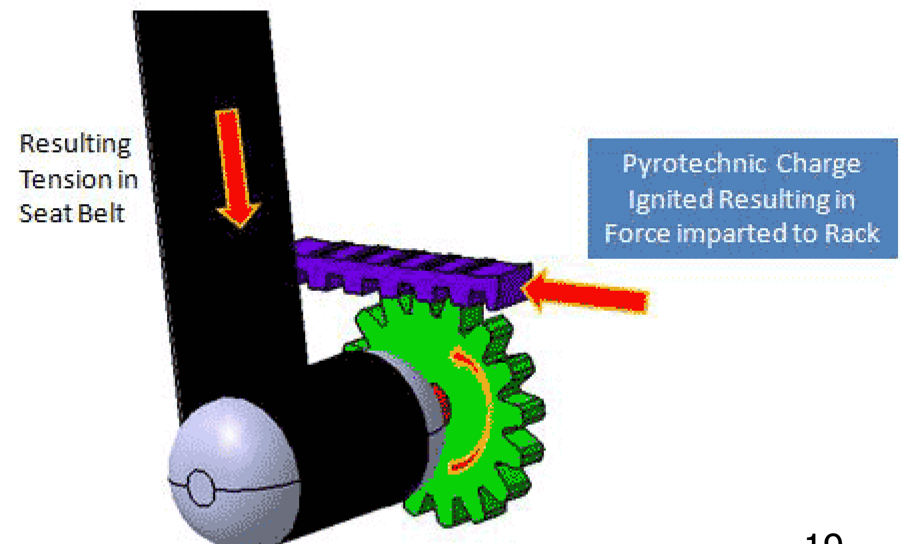


Seat belts



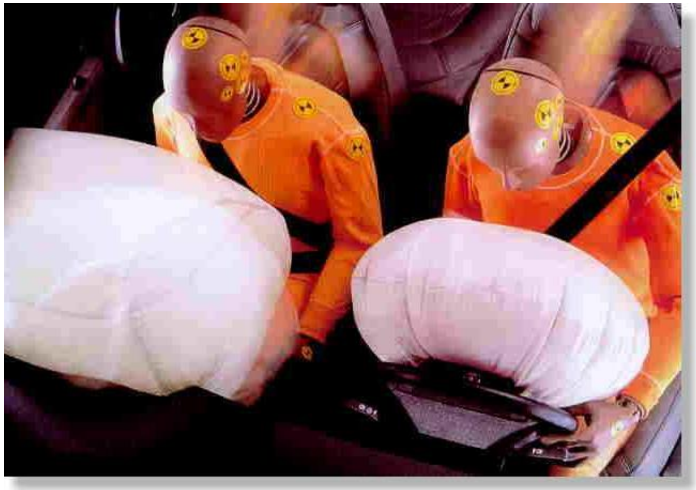
- The second factor of passive safety are the seat belts and its later developments like pre-tensioners

Figure 1: Pyrotechnic Pretensioner basic design

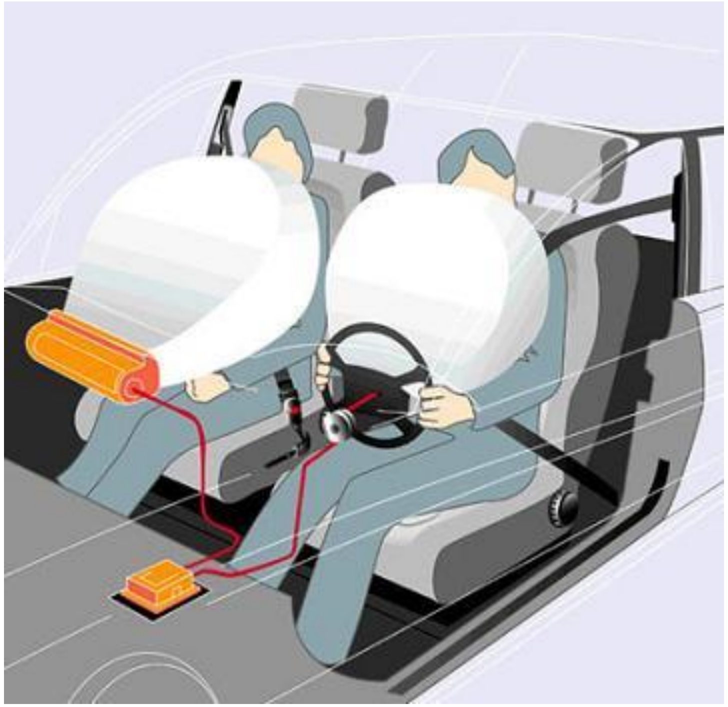


Airbags

- Airbags are mitigating the shocks of body parts (especially the head) against the interior part of the vehicle
- There is now an expansion of airbag types: frontal, side, heads and even external ones for pedestrian shocks



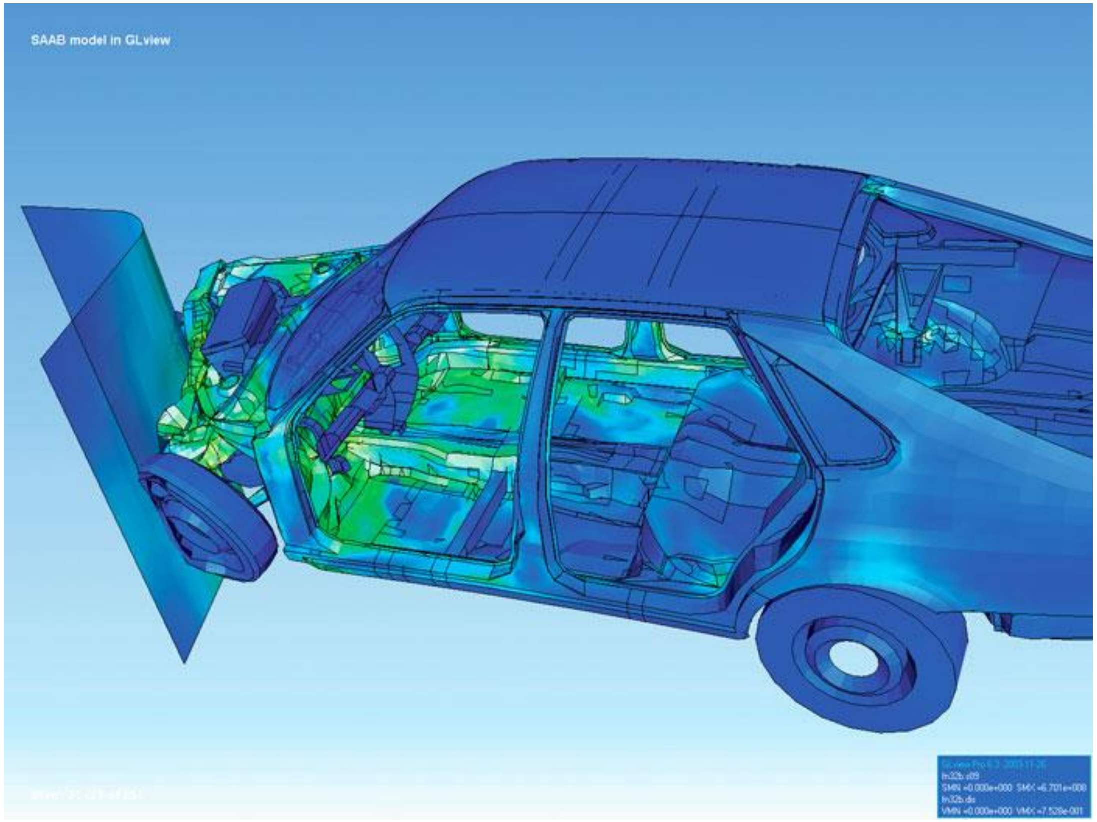
Airbags



Structural integrity

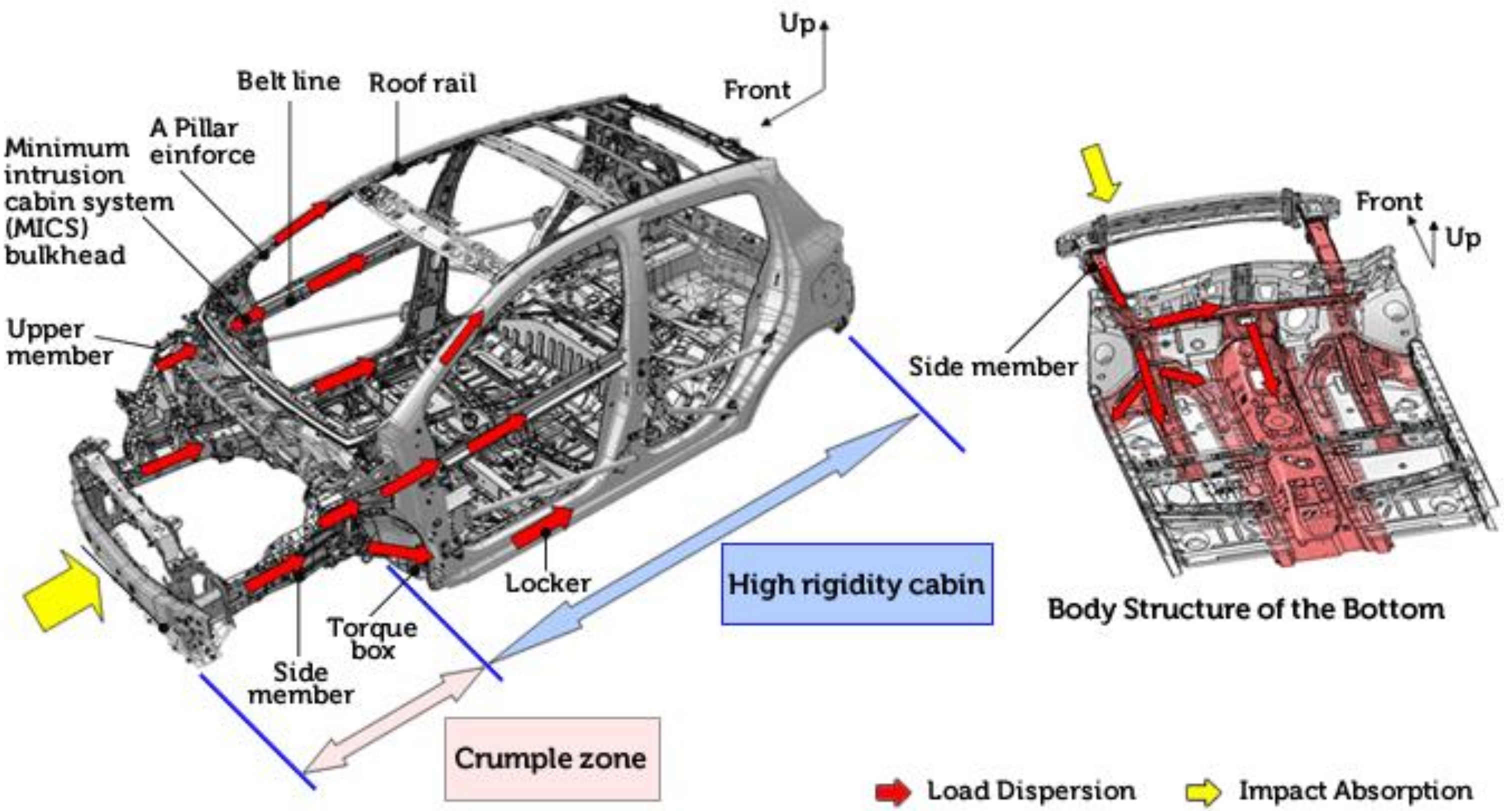
- By law, all new car models must pass certain safety tests before they are released on the market.
- Legislation provides a minimum statutory standard of safety for new cars.
- The aim of Euro NCAP is to encourage manufacturers to exceed these minimum requirements.

Structural integrity

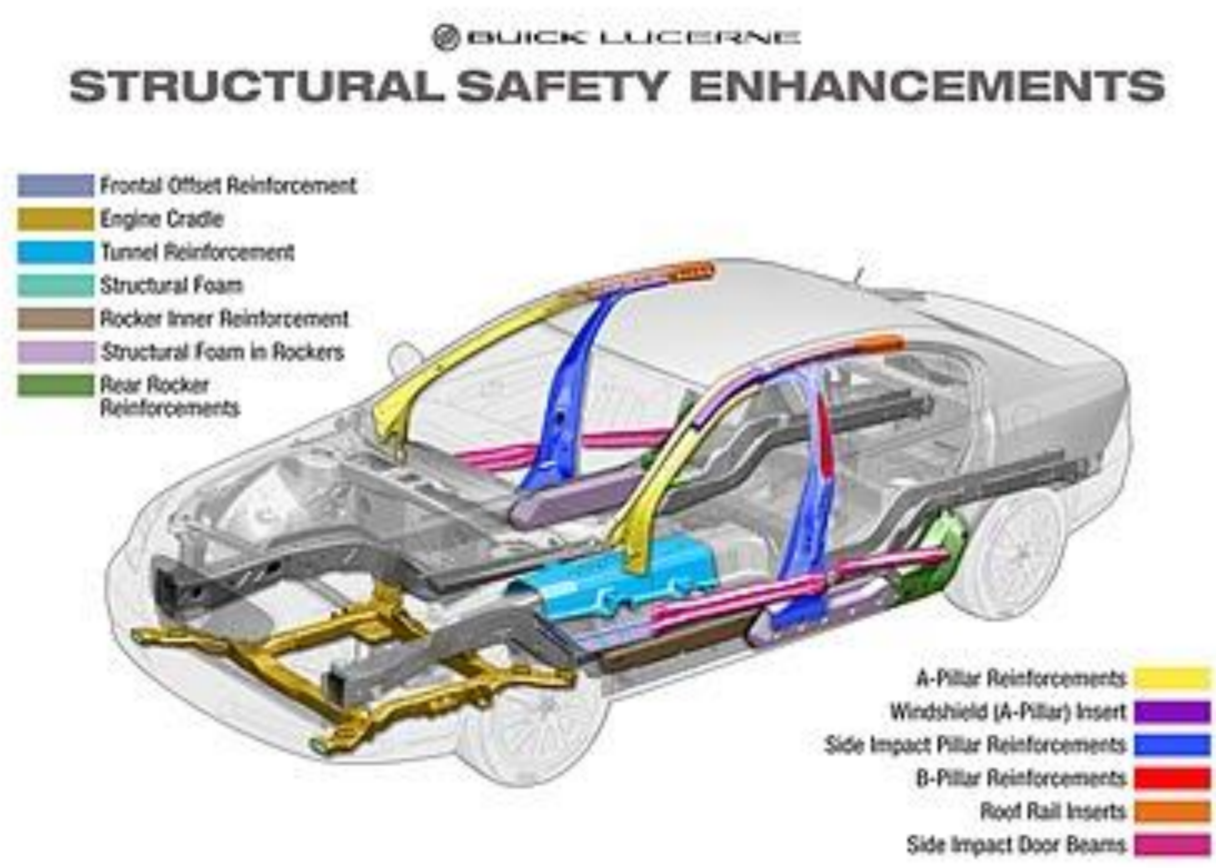


Crumble zones in modern structures of car body for improved safety

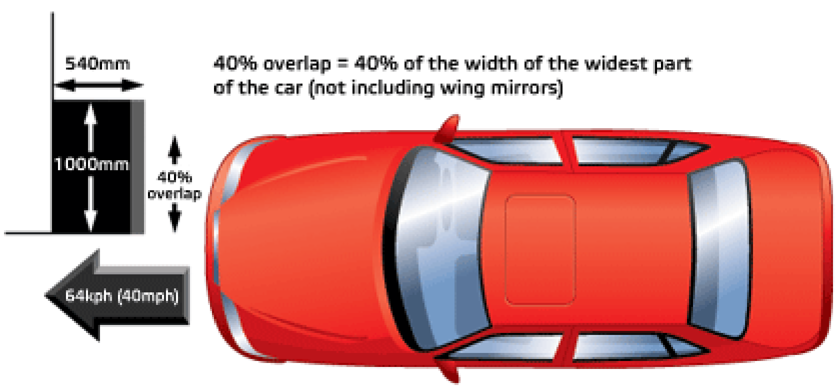
Structural integrity

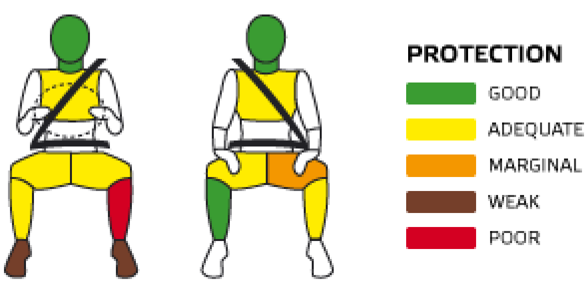


Structural integrity



EURO NCAP

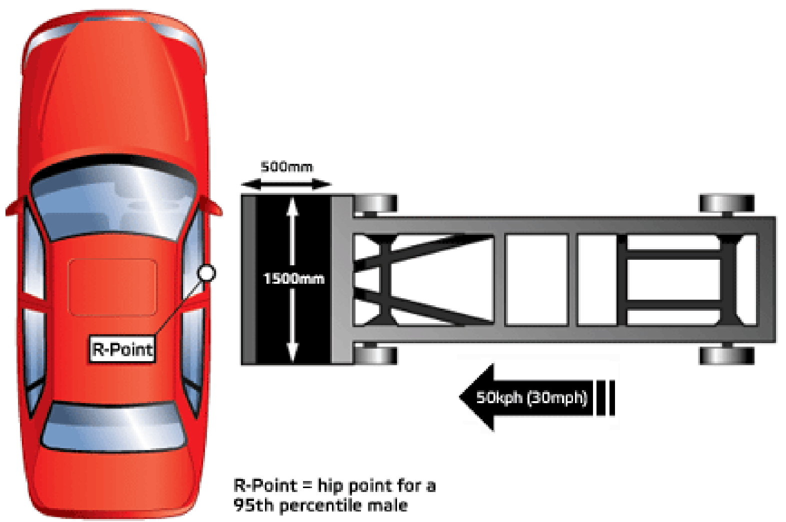




FRONTAL IMPACT

- Frontal impact test is based on that developed by European Enhanced Vehicle-safety Committee as basis for legislation, but impact speed has been increased by 8 km/h.
- Frontal impact takes place at 64kph, car strikes deformable barrier that is offset.

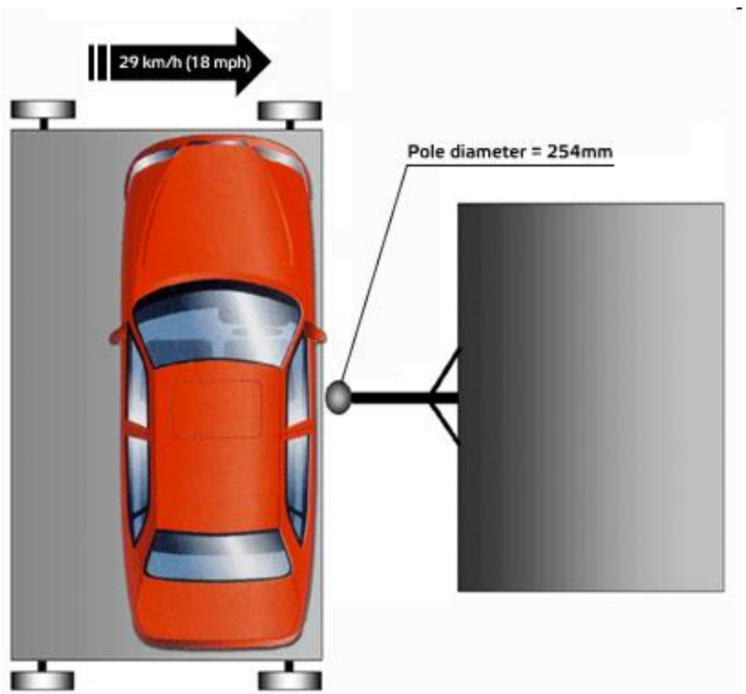
EURO NCAP



SIDE IMPACT

- The second most important crash configuration is the car-to-car side impact. Euro NCAP simulates this type of crash by having a mobile deformable barrier (MDB) impacting the driver’s door at 50 km/h. The injury protection is assessed by a side impact test dummy, in the driver’s seat.

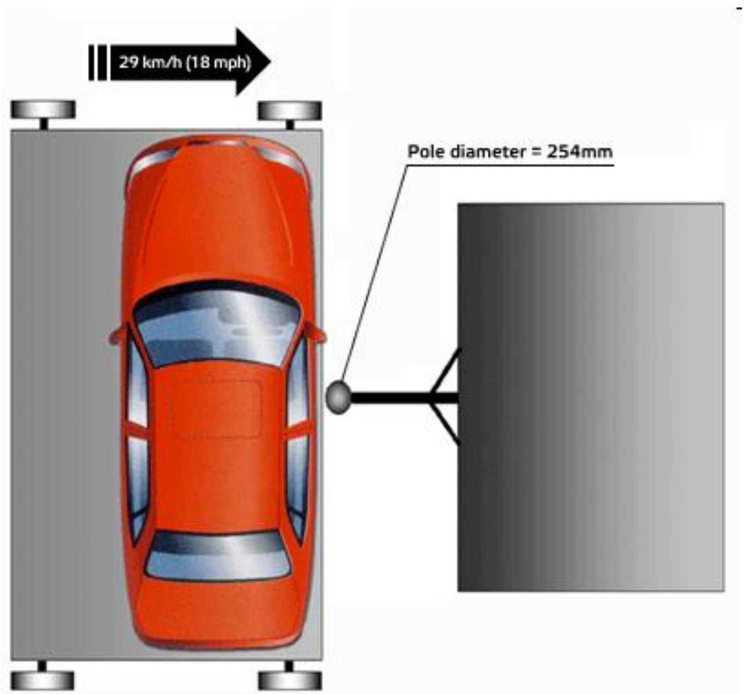
EURO NCAP



SIDE IMPACT

- Pole test: Approximately a quarter of all serious-to-fatal injuries in EU happen in side impact collisions. Many of these injuries occur when one car bumps into the side of another or into a fixed narrow object such as a tree or pole.

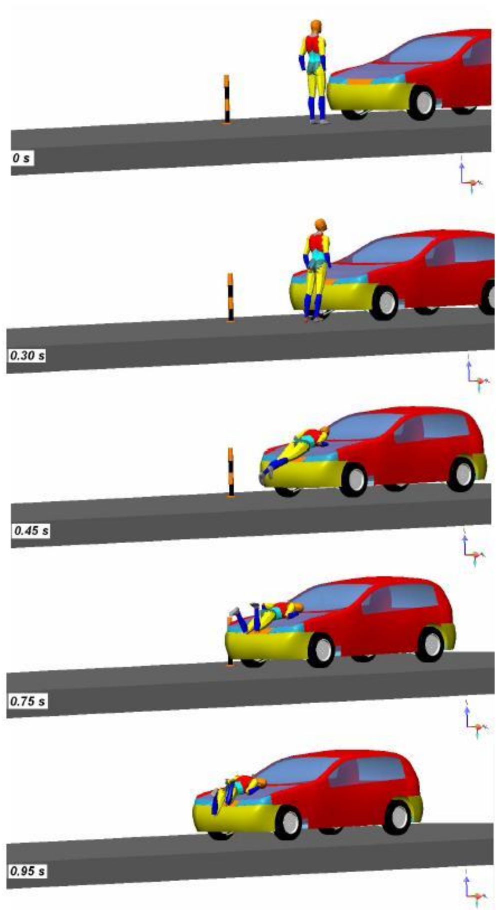
EURO NCAP



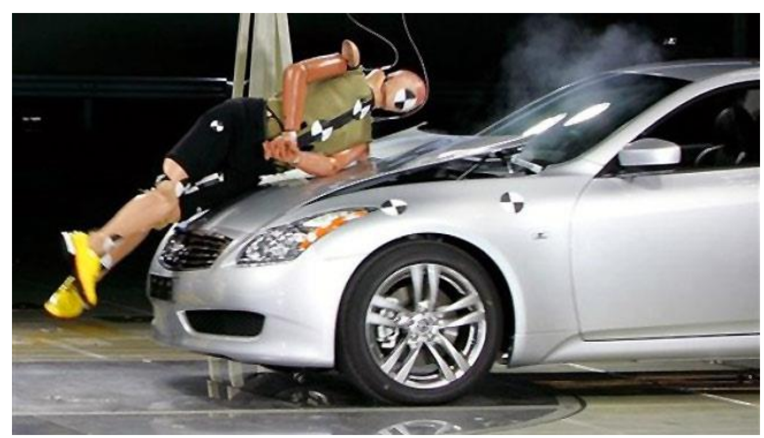
SIDE IMPACT

- To encourage manufacturers to fit head protection devices, pole test may be performed, where such safety features are fitted. Side impact head or curtain airbags help to protect the head and upper torso by providing a padding effect and by preventing the head from passing through the window opening. In the test, the car tested is propelled sideways at 29kph into a rigid pole. The pole is relatively narrow, so there is a major penetration into the side of the car.

Pedestrian protection

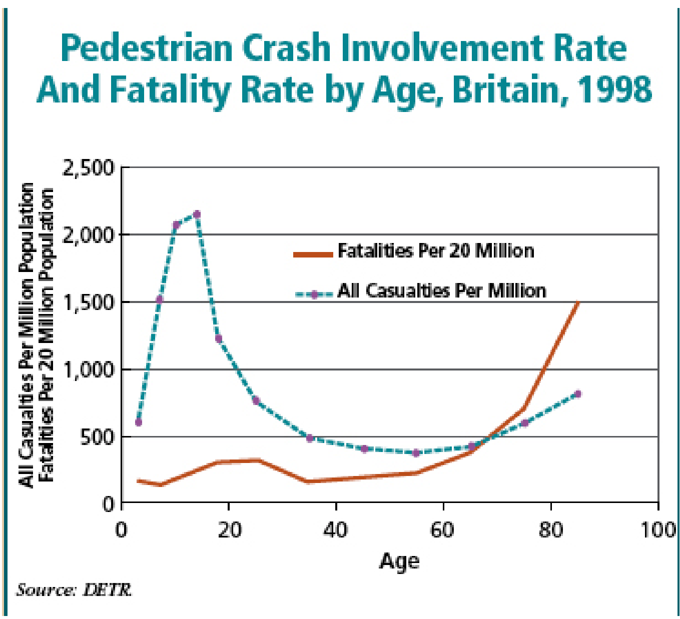


- After having improved the occupant protection, the legislator is now trying to improve the third party's injuries, in particular the pedestrians.
- This resulted in several measures
  - Face lift agreement
  - Modification of the car hood

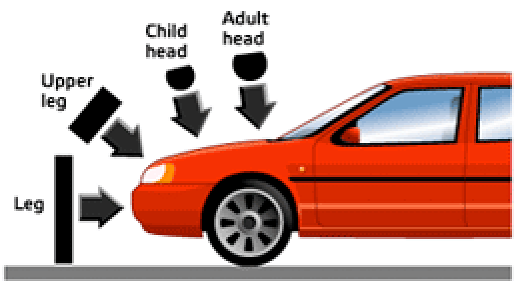


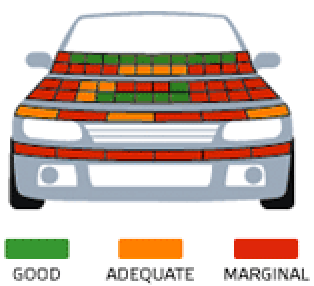
Pedestrian protection

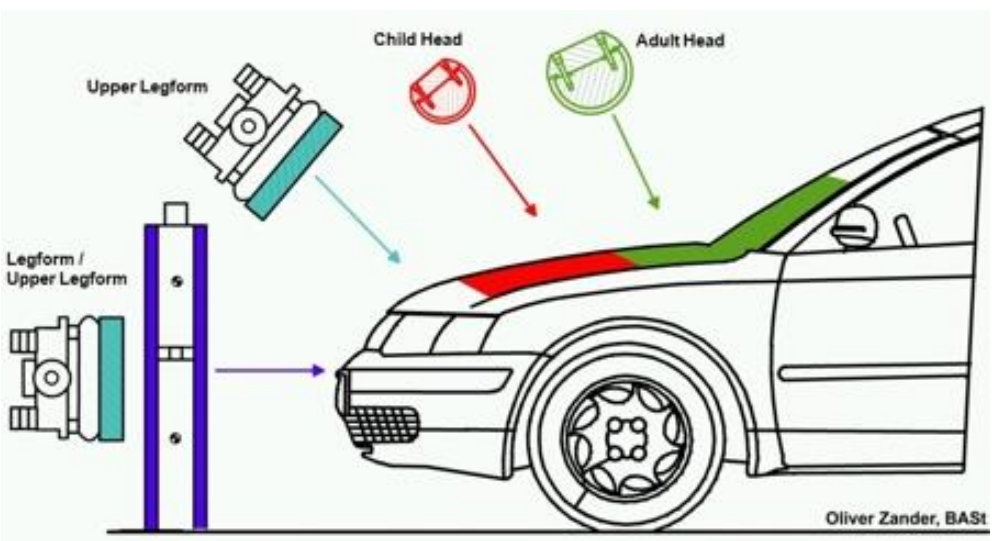
- Pedestrian are weak users of the roads.
- Reducing the number of fatalities and injuries is a great challenge of sustainable roads



Pedestrian protection







- EURO NCAP
- A series of tests are carried out to replicate accidents involving child and adult pedestrians where impacts occur at 40kph. Impact sites are then assessed and rated fair, weak and poor. As with other tests, these are based on European Enhanced Vehicle-safety Committee guidelines

Pedestrian protection

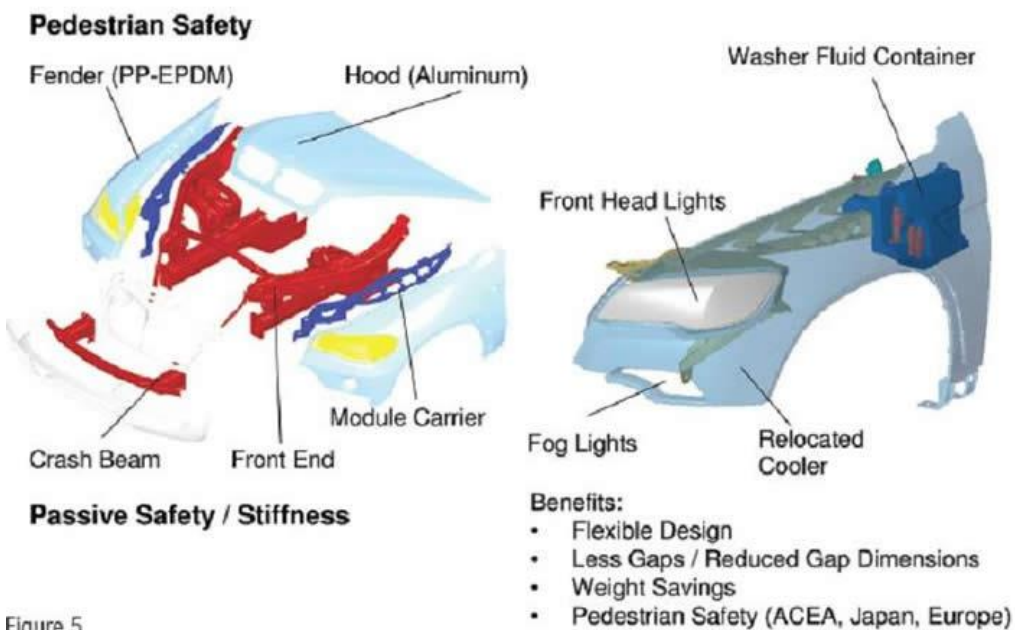
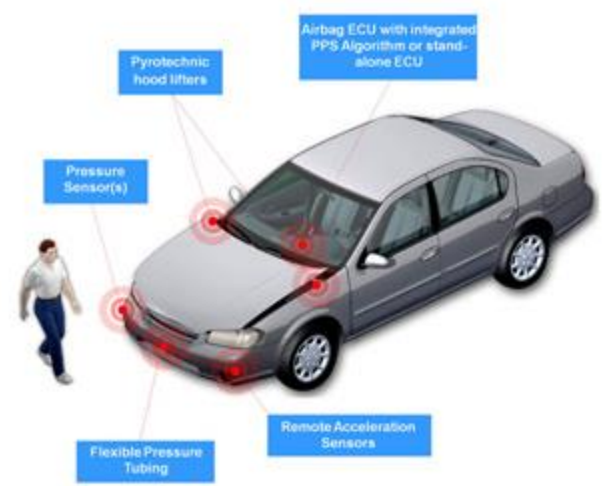


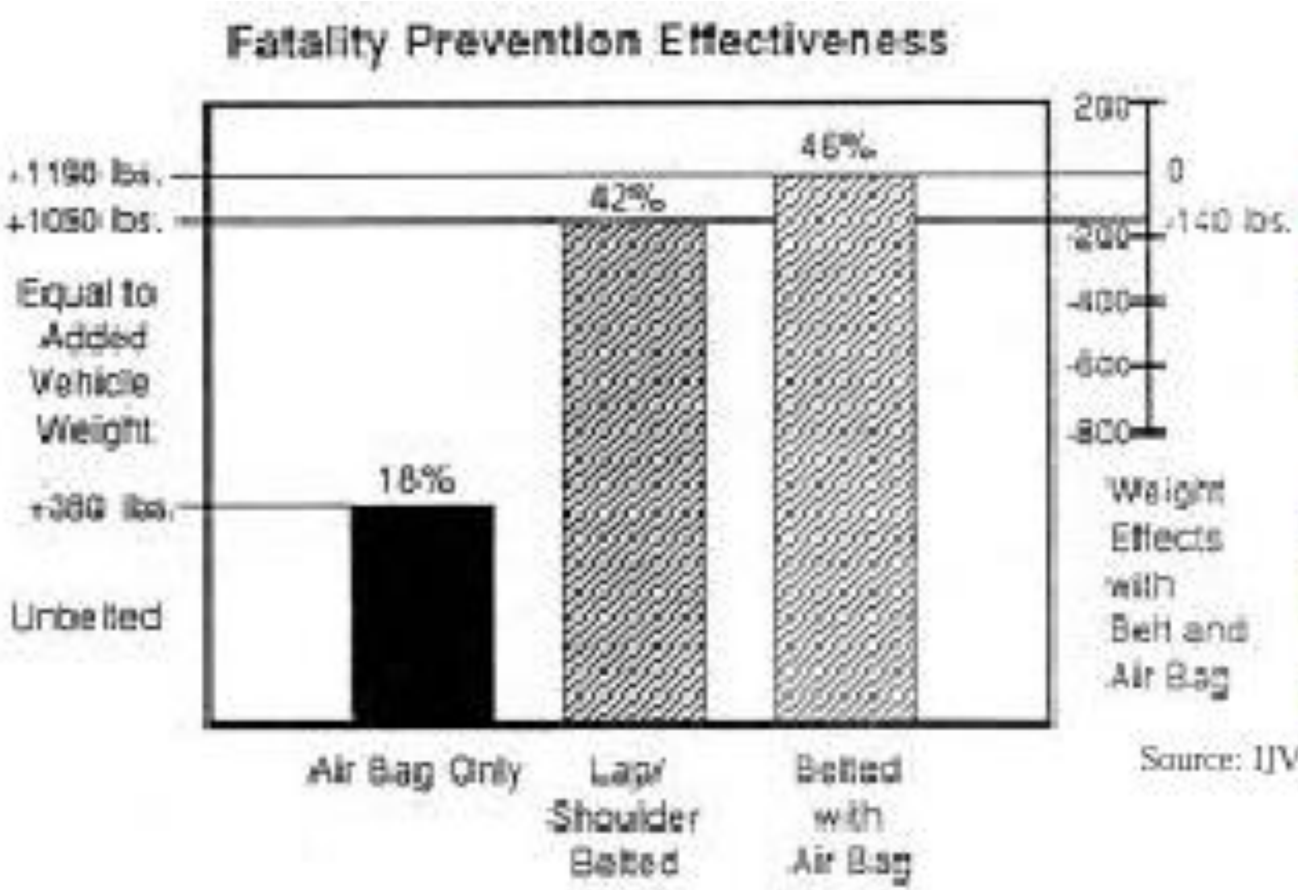
Figure 5



ACTIVE SAFETY SYSTEMS

- Why active safety systems?
  - The (on-board) passive safety systems have shown a lower pay-back than expected
    - In terms of saved lives if we compare to the extra mass that we pay for a given increase of safety
  - Antagonistic issue between the mass to increase the safety and the reduction of the mass to increase the fuel economy
    - Moreover the aggressive character of certain types of vehicles as the SUV
  - The human error is responsible for 75% to 90% of the road accident. Human error can not be reduced by passive safety systems.

Passive safety

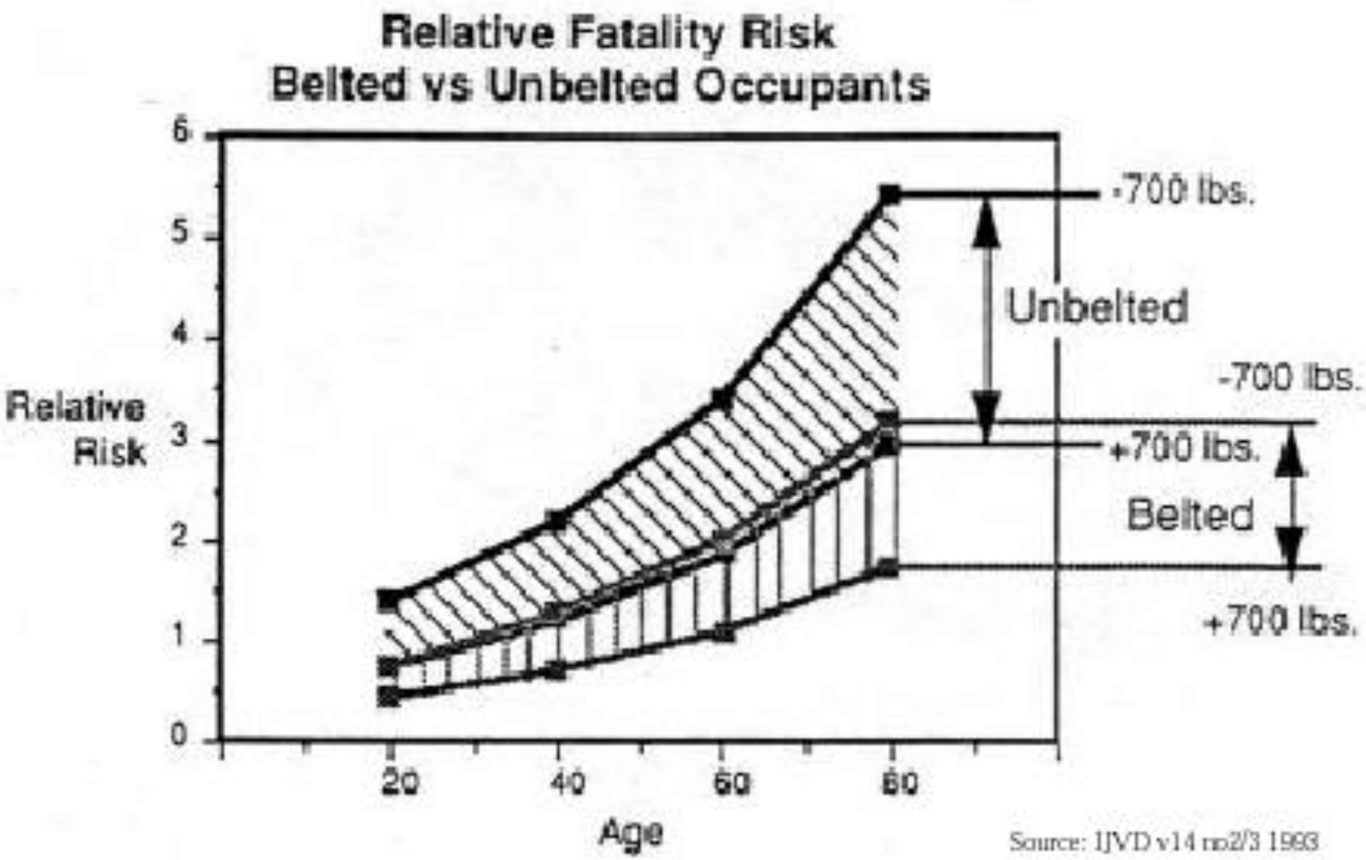


Diminish in returns

Benefit of Airbag offset by weight reduction of **140 lb**

Source: IJVD v14 no2/3 1993

Passive safety

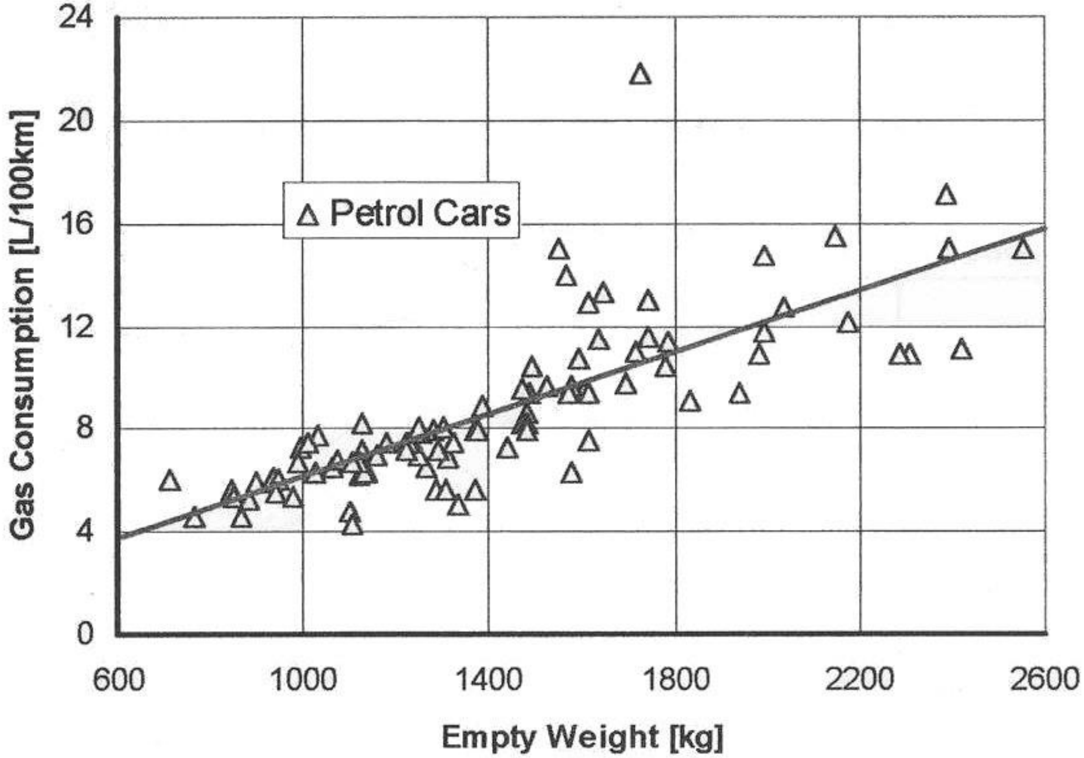


Effect of mass reduction

- Following the CAFÉ (Corporate Average Fuel Economy) recommendation and other environmental constraints, there is great pressure to reduce the weight of cars.
- The reduction of the weight has a very negative impact on the safety:
  - In the USA, one estimates that a weight reduction of 50 kg would result in an increase of 10543 wounded persons on the road.
  - Moreover, studies show that the difference of mass between colliding vehicles is a great source of fatalities
    - For instance, Gabler & Fildes (SAE paper 1999-01-069) estimates that the probability of fatalities F1 and F2 in the two vehicles of mass M1 and M2 is related by a power law

$$\boxed{\frac{F_2}{F_1} = \left(\frac{M_1}{M_2}\right)^4}$$

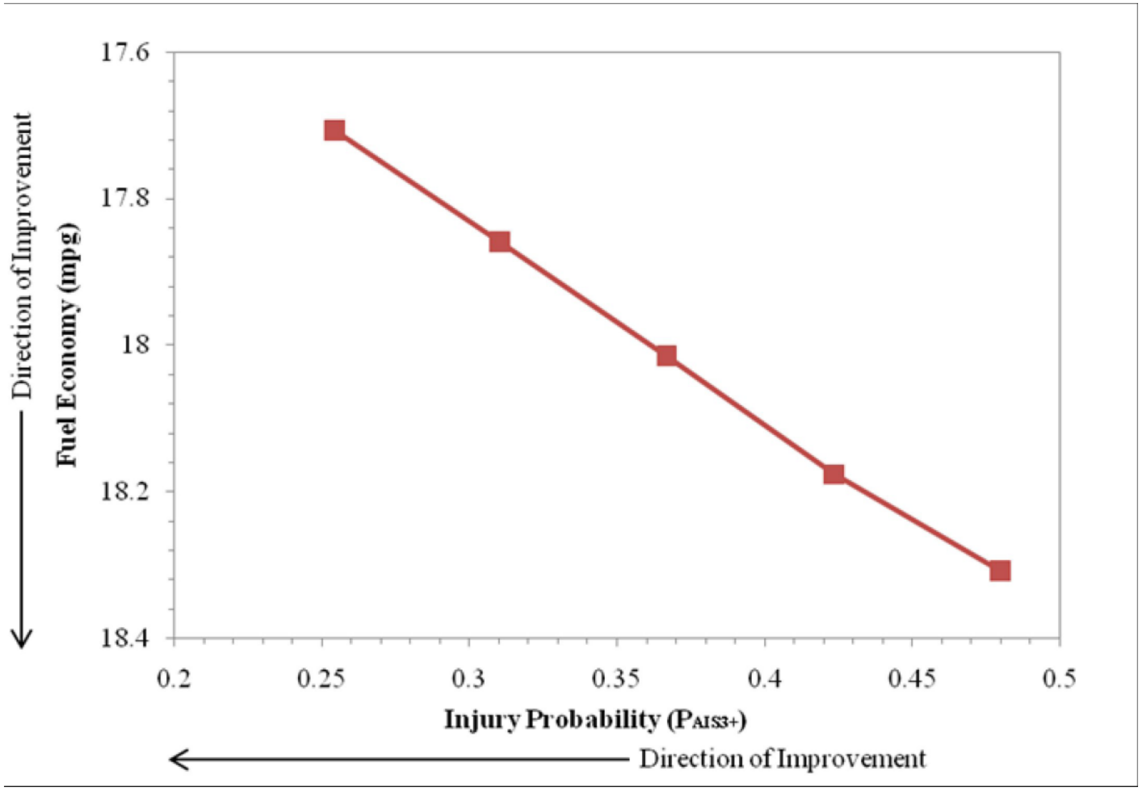
Effect of mass reduction



Roel Boesenkool
SMEA conference

- Generally one estimates that 10% of mass reduction results in an average reduction of 6% of the fuel consumption

Conflict between mass reduction and fuel consumption



- S. Hoffenson, P. Papalambros, M. Kokkolaras, M. Reed. An optimization approach to occupant safety and fuel economy in vehicle design. 8th World Congress on Structural and Multidisciplinary Optimization June 1 - 5, 2009, Lisbon, Portugal

Aggressivity of SUV

- Following the statistics of the NHTSA (National Highway Transportation Safety Association) (1999) the probabilities of fatalities in a crash with a SUV or light duty vehicle is increased by 2 to 4 compared to a medium size car

Collision: Accord vs. Explorer

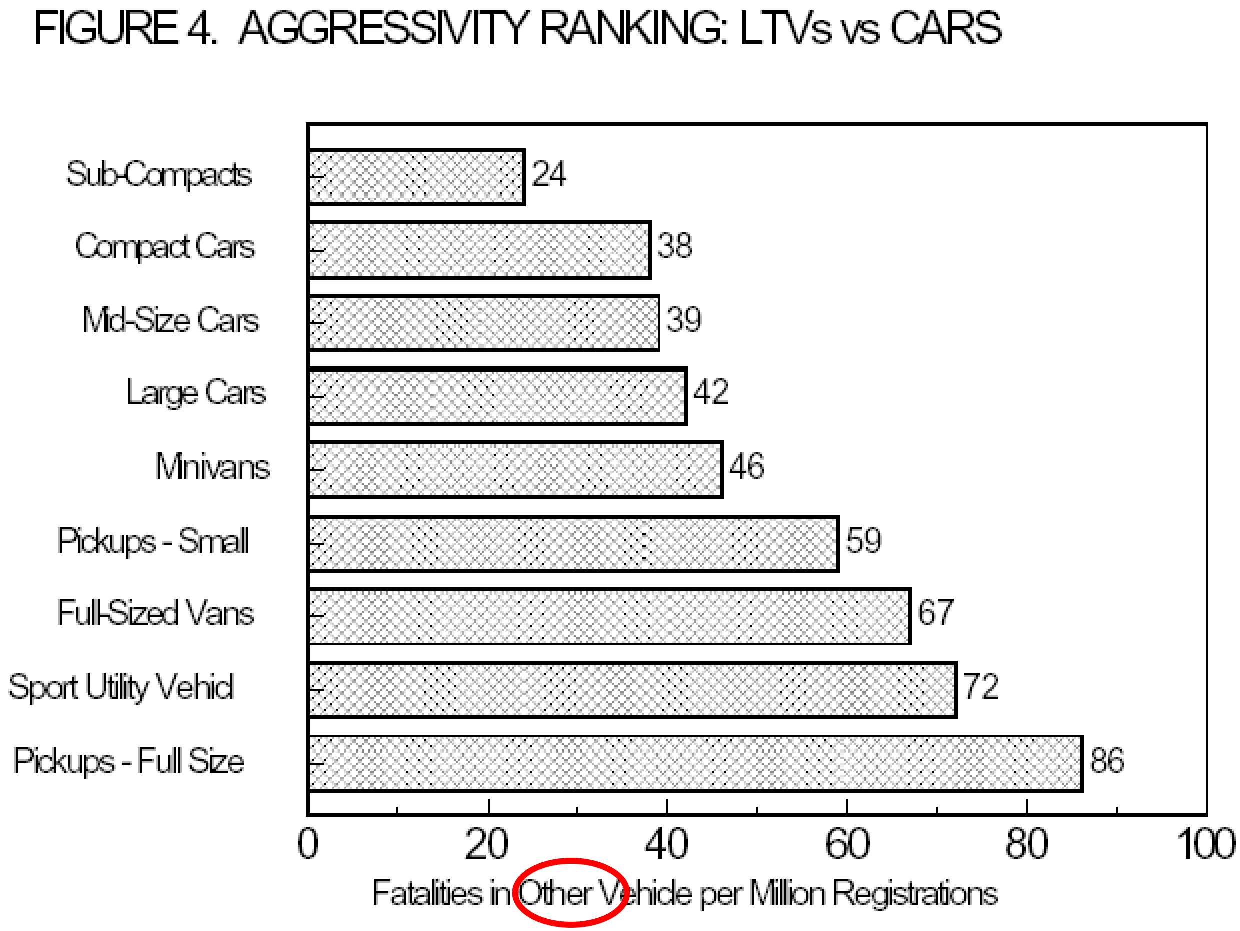
Scenario: offset crash, both vehicles move at 35mph

Aggressivity of SUV

- Crash test between an Audi Q7 and a Fiat 500 made by ADAC

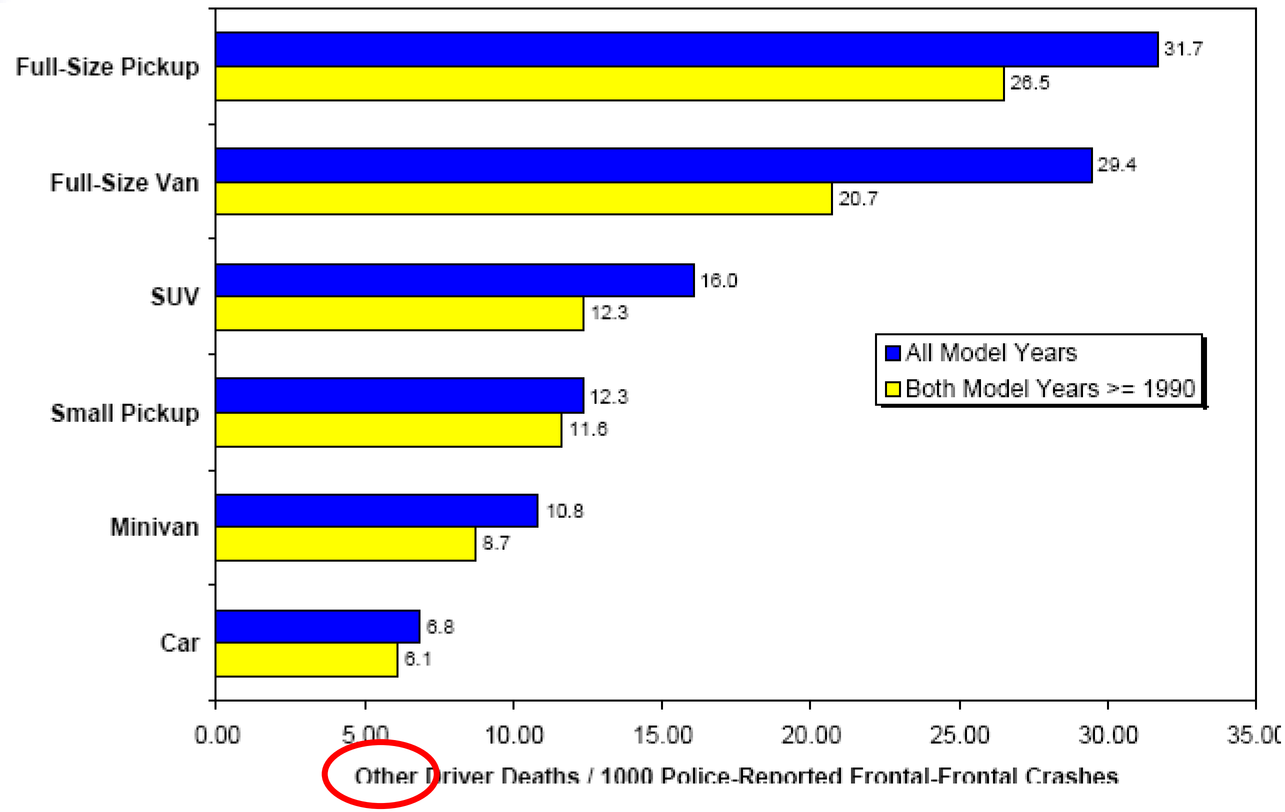
  https://www.youtube.com/watch?v=6pVF1Wr7GLQ

Aggressivity of SUV



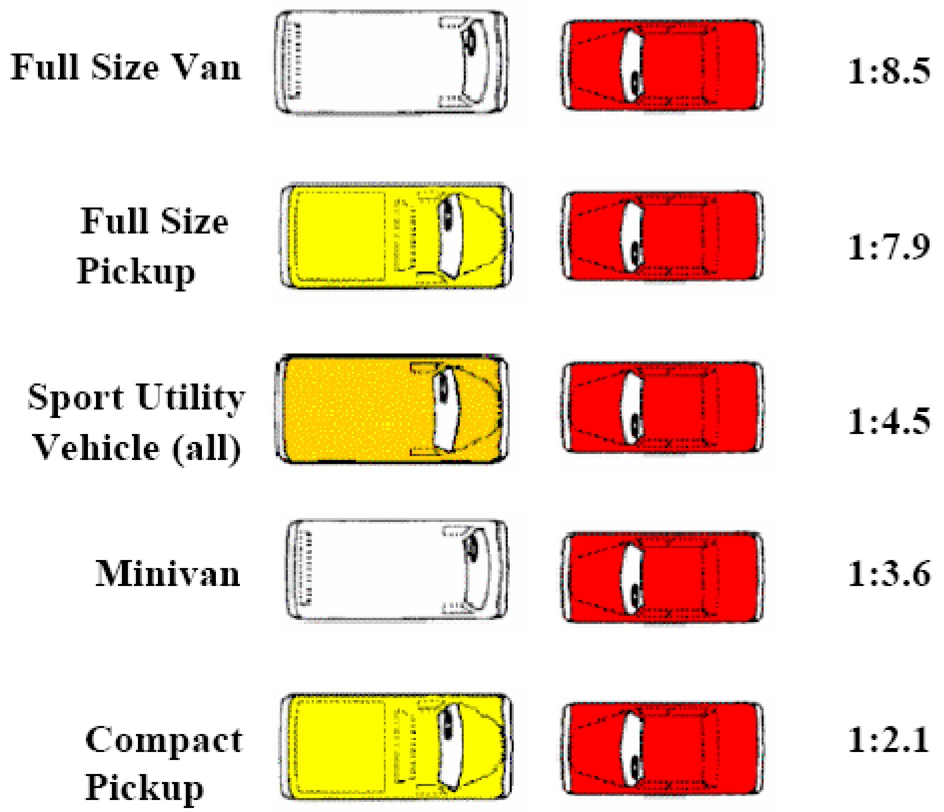
Hollowell & Gabler, NHTSA paper 96-S4-O-01

Aggressivity of SUV



Hollowell & Gabler, NHTSA paper 98-S3-O-01

Aggressivity of SUV



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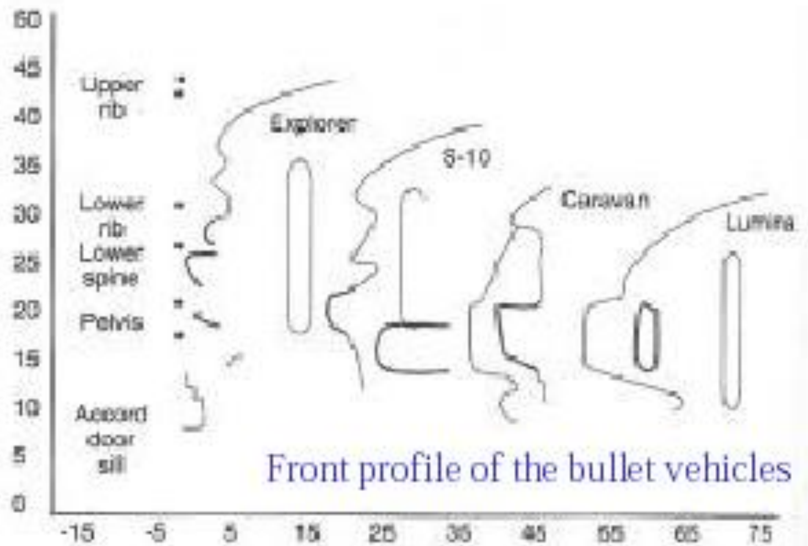
Aggressivity of SUV



NHTSA vehicle compatibility research project

Ford "blockerbeam" for 2000 Excursion to prevent cars from sliding underneath during a frontal collision

Aggressivety of heavy vehicles

- Following the statistics of the NHTSA (National Highway Transportation Safety Association) (1999) the probabilities of fatalities in a crash with a SUV or light duty vehicle is increased by 2 to 4 compared to a medium size car

PART II : ACTIVE SAFETY

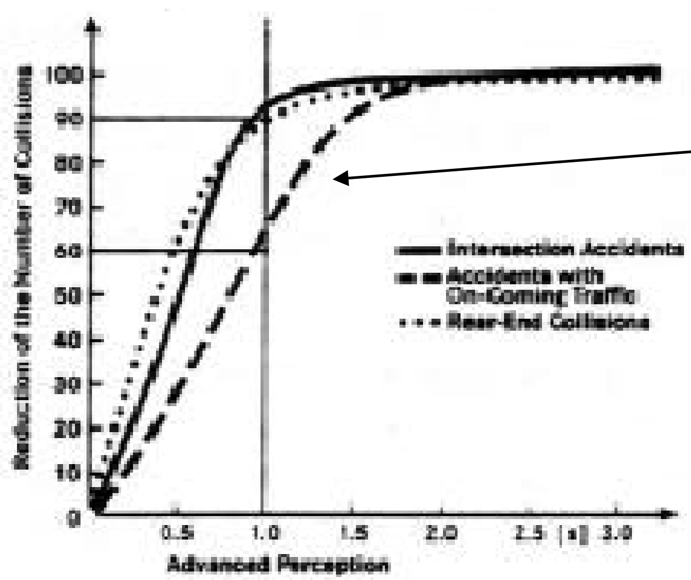
Active safety systems

- Active safety systems are all systems that aims at preventing the crash or reducing its severity before it happens.

- Examples of systems
  - Antilock Bracking System (ABS)
  - Traction Control Systems (TCS)
  - Vehicle Dynamics Control (VDC)
  - (Electronic Stability Program - ESPTM)
  - Roll over detection
  - Electronically Controled Suspension (ECS)
  - Intelligent tyre

Why active system? Human errors

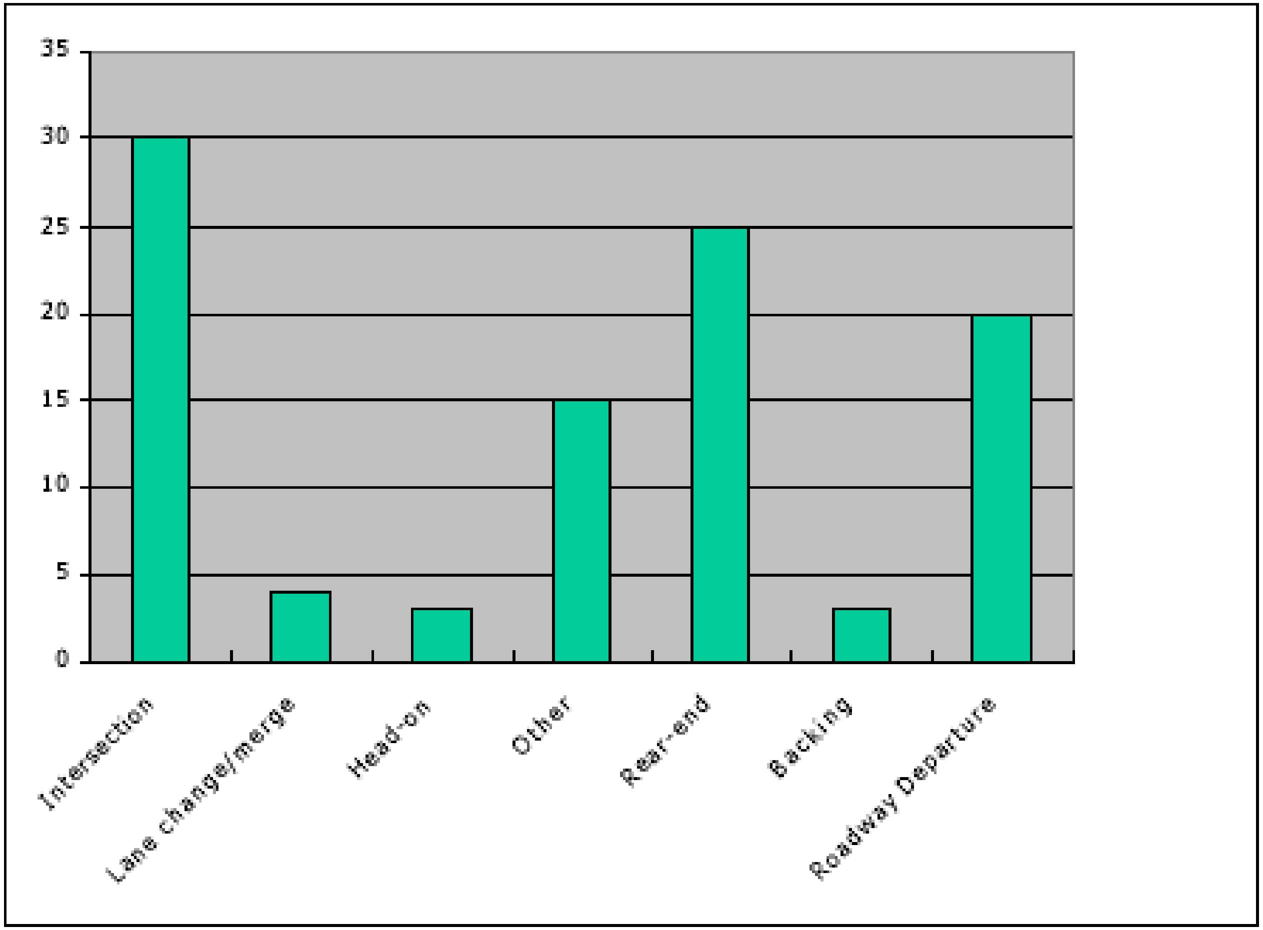
- Human errors is responsible for 75% of road accident for passenger cars and 80 to 90% for accident with duty vehicles.
- The reaction time of human people (average time is 0,75 sec) is the source of a dangerous situation for the vehicle and for the traffic.



If a warning signal was emitted 0,5 (1,0) sec before crash, it could avoid 30 to 60% (or 60 to 90 %) of the accidents !

Source: von Glasner AVEC'94 002 9437953

Active safety: the targets



NHTSA 1991 results (published in 1994)

Active safety: the targets

- Rear-end crash (as well as frontal): 25 % (28%) of accidents
  - Measure of the field (or its variation) can give a warning scheme based on the time-to-collision
- Lane departing: 20% of accidents – 36% of fatalities
  - Measure of the lane departing. Warning based on the lane crossing
- Lateral and back crash: 7% of accidents
  - Proximity detector (with a sonar sensor for instance). Warning based on the detection of object detection and time-to-collide
- Intersections: 30% of crashes
  - Wide detection using large angle sensors, intersection directions in order to identify the possible collisions

Warning system for rear-end collision

- Working principle:
  - Identify a target
  - Measure the distance, the rate of distance change, and the vehicle speed
  - Predict the vehicle trajectory
  - Warning algorithms based on
    - Time before collision
    - Estimation of the vehicle speed, the friction coefficient, the human reaction time (reaction, judgment).

- Weakness and difficulties:
  - Wrong warnings and noisy signals

Anti-lock braking systems

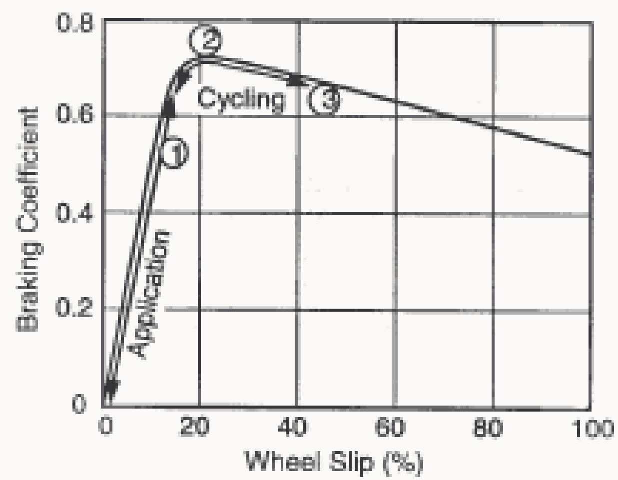


Fig 3.11 ABS operation to stay at the peak braking coefficient.

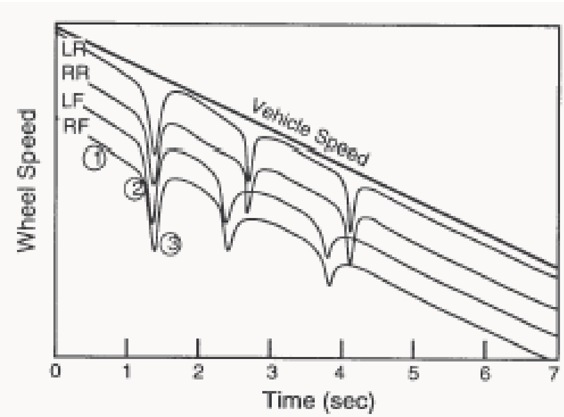


Fig. 3.10 Wheel speed cycling during ABS operation.

- The ABS (Anti-lock Brake System) monitors the speed of each wheel to detect locking.
- When it detects the wheel locking, it releases braking pressure for a moment and enables the wheel to reaccelerate
- By a sequence of braking / releasing ABS provides optimum braking pressure to each wheel.

Anti-lock braking systems

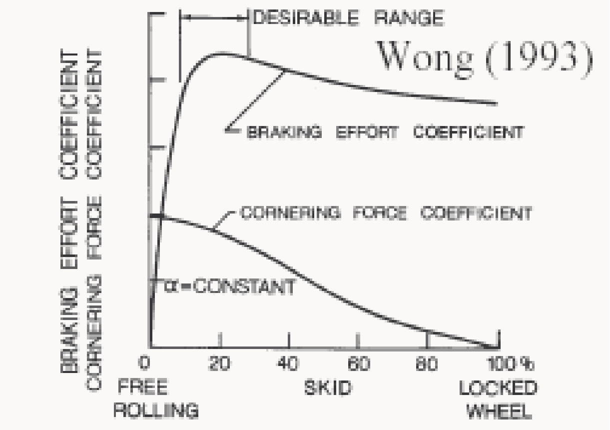
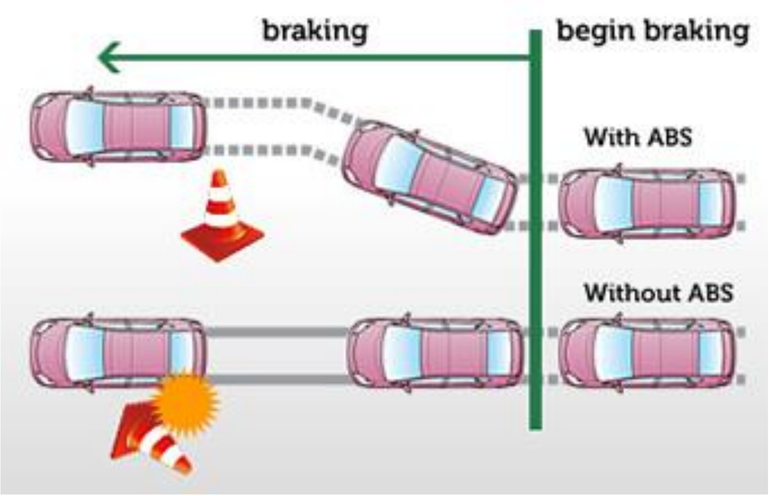


Fig. 3.54 Effect of skid on cornering force coefficient of a tire.

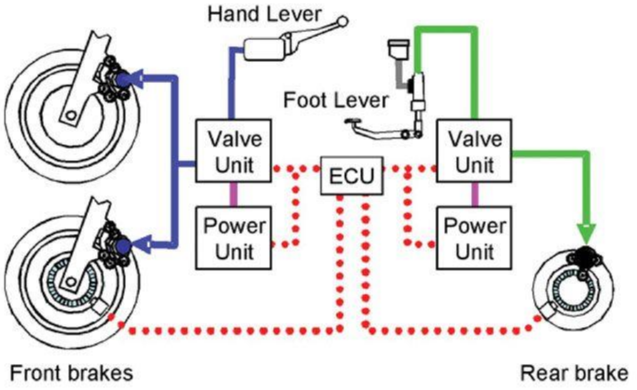


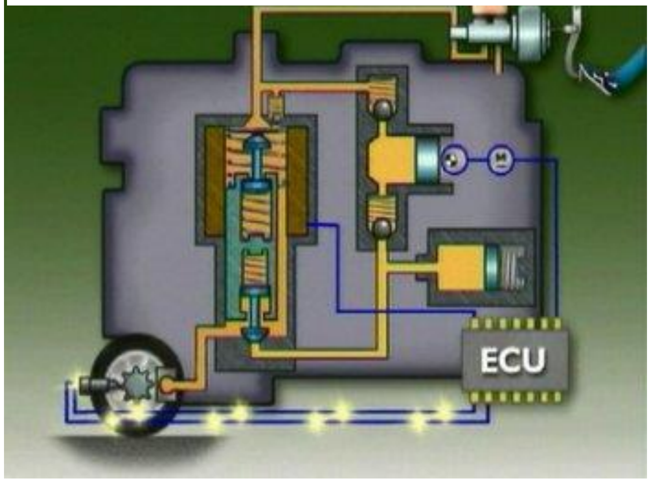
- By limiting the longitudinal slip, it preserves the lateral force capability and helps improving the ability of stopping the vehicle in stable conditions
- ABS generally reduces the braking distance but not always. The major contribution of ABS is to be able to keep the control of the car during braking maneuver even in turning conditions

Anti-lock braking systems

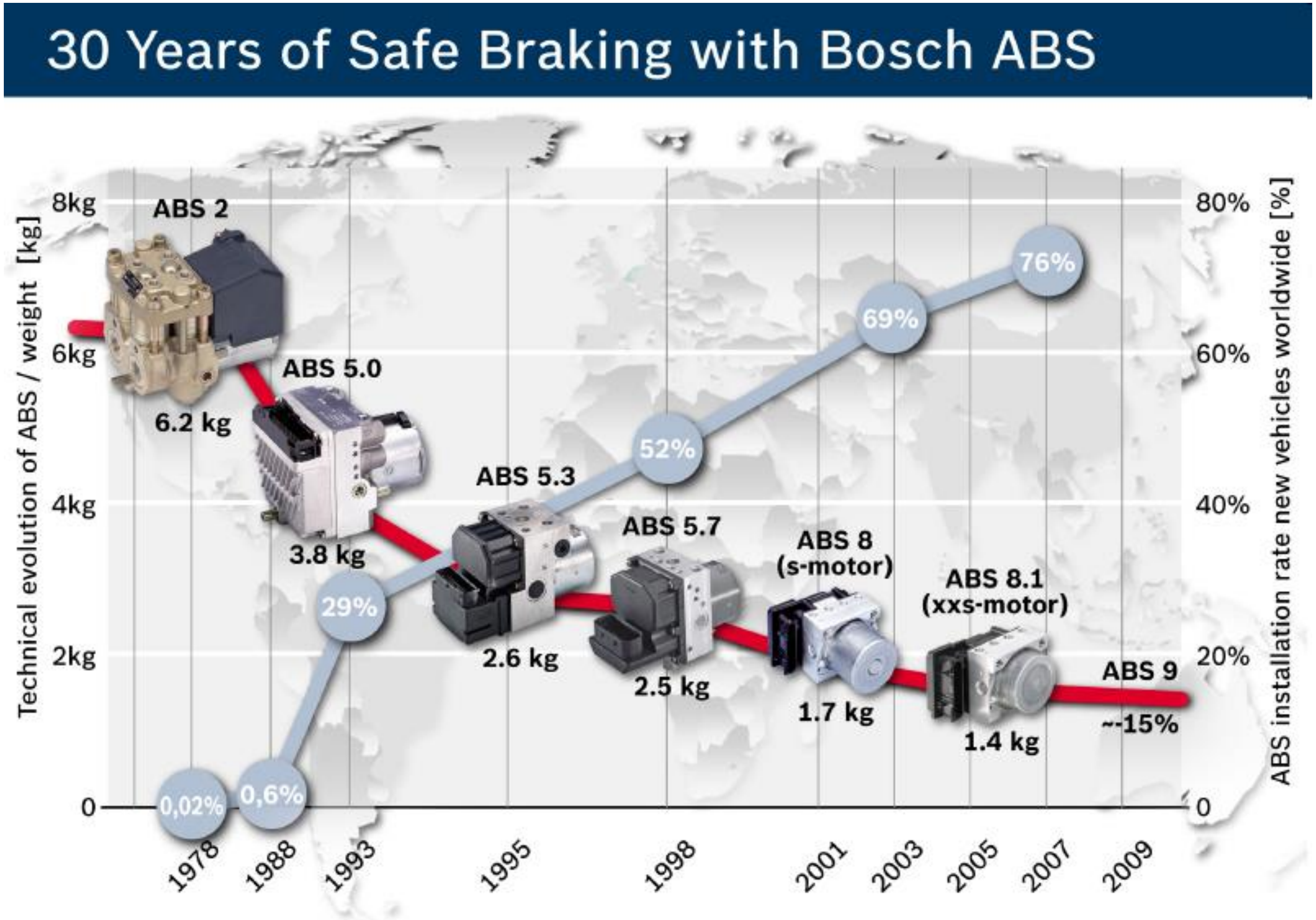
The ABS system includes:

- Wheel speed sensors
- Pressure sensors
- An ECU system that will detect the locking and will manage the cycles of pressure increase and decrease
- A hydraulic valve that is able to connect the brake piston to hydraulic power source or to the return circuit





Anti-lock braking systems



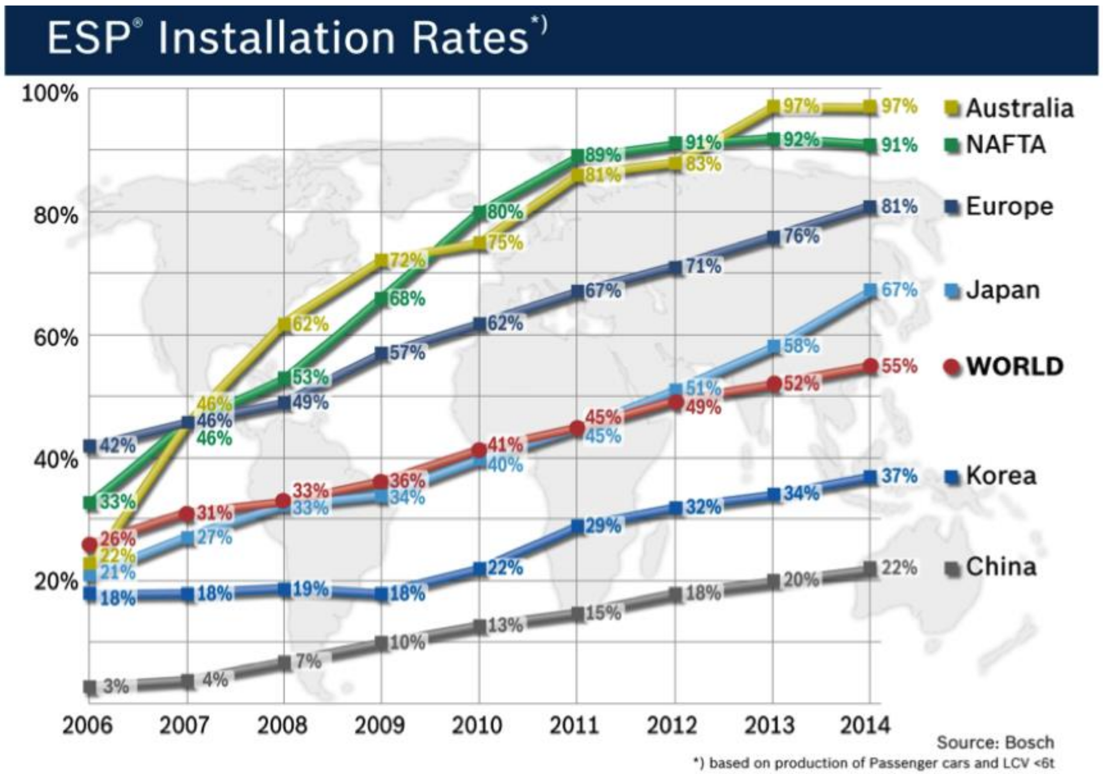
Vehicle Stability program

- The ESP system aims at insuring the control of the lateral dynamics of the vehicle in any circumstances
- One major commercial name ESP = Electronic Stability Program
- The Bosch ESP relies on the braking system to achieve the directional control of the vehicle and its stability
- The ESP is an evolution (or a revolution?) of former systems ABS, TCS and relies on these technologies. The ESP goes far beyond of the objectives of these systems.
- When the ESP function is on, the braking system priority is modified. When ESP intervenes, the fundamental functions of the braking systems (braking and stopping the vehicle) are put on the back to insure the stability of the vehicle

Vehicle Stability program

- ESC addresses the problem of skidding and crashes due to loss of control of vehicles, especially on wet or icy roads or in rollovers.
- Evaluation studies have shown that the fitment of ESC in cars can lead to substantial reductions in crashes, deaths and serious injuries.
  - A Swedish study in 2003 showed that cars fitted with ESC were 22% less likely to be involved in crashes than those without. There were 32% and 38% fewer crashes in wet and snowy conditions respectively.
  - In Japan, a study showed that electronic stability reduced crash involvement by 30-35%
  - In Germany, one study indicated a similar reduction while another showed a reduction in 'loss-of-control' crashes from 21% to 12%.

Vehicle Stability program



- Nowadays the ESC shows a high penetration of the market for new vehicles: 55%

Vehicle Stability program

- The operation of ESP plays with an independent braking of the four wheels. Example:
  - Braking on the rear wheel to control the under steer
  - Braking on the front wheel to counteract an over steer

Fig. 1

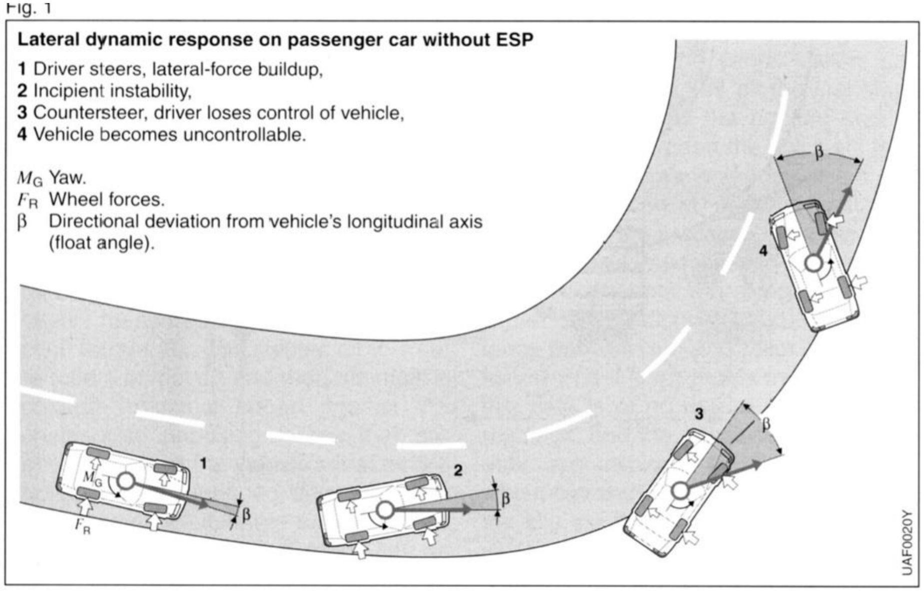
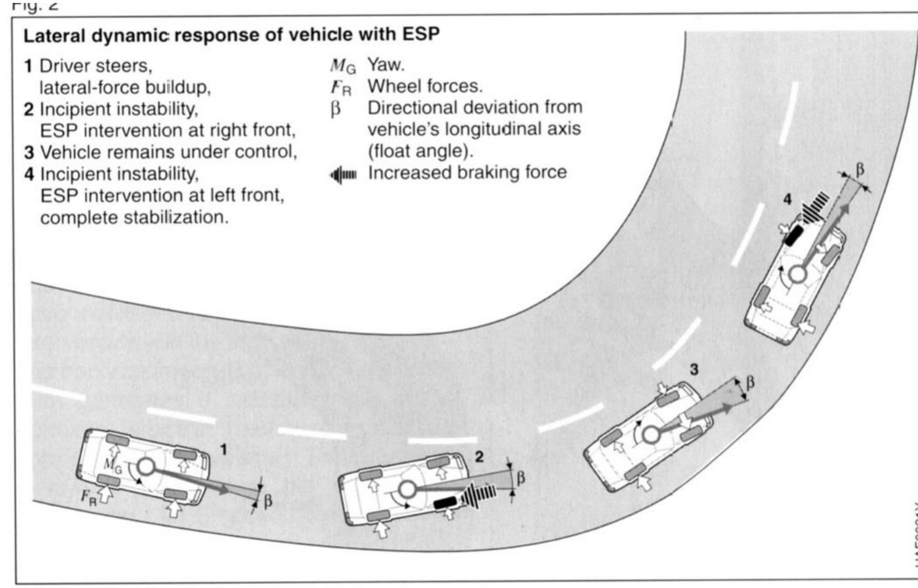


Fig. 2



Vehicle Stability program

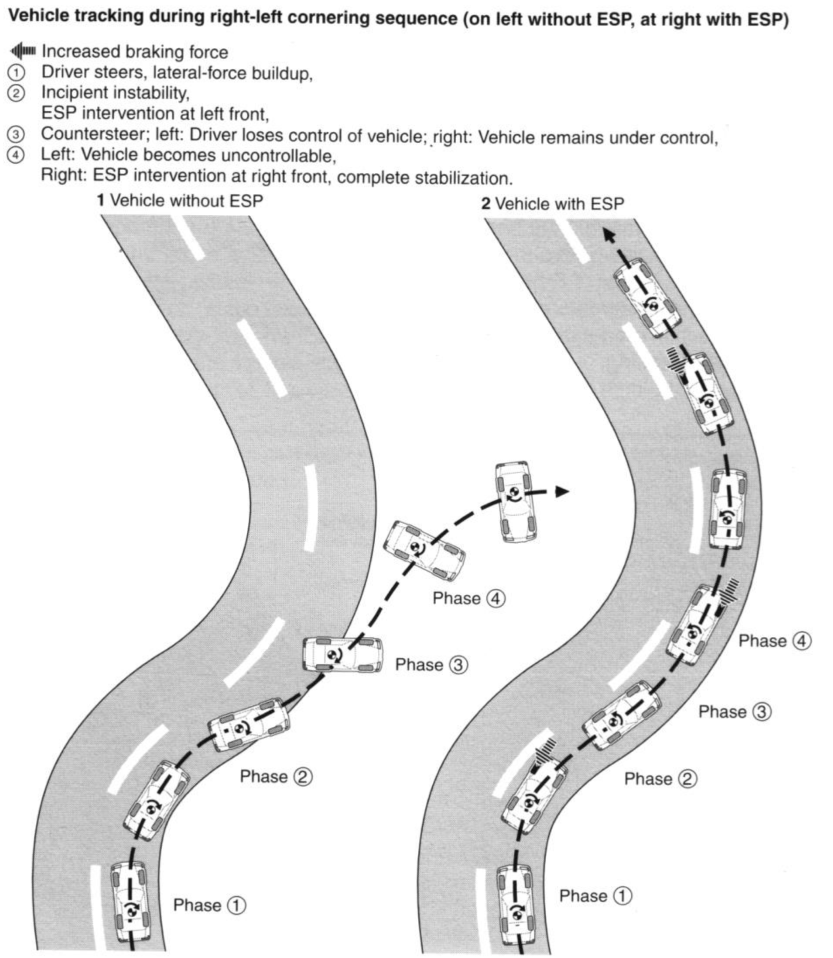
- For a maximum efficiency, the ESP operates with independent wheel braking, but also with the engine electronic control unit to accelerate or reduce the torque under the driven wheels.
- The ESP has two complementary strategies:
  - Differential braking on independent wheels
  - Modulation of the torque on the driven wheels
- The ESP helps to maintain the vehicle on the road within the capability of physics
  - Reduction of the roll-over
  - Reduction of the accident probability
  - Improving the safety by providing an active support to the driver.

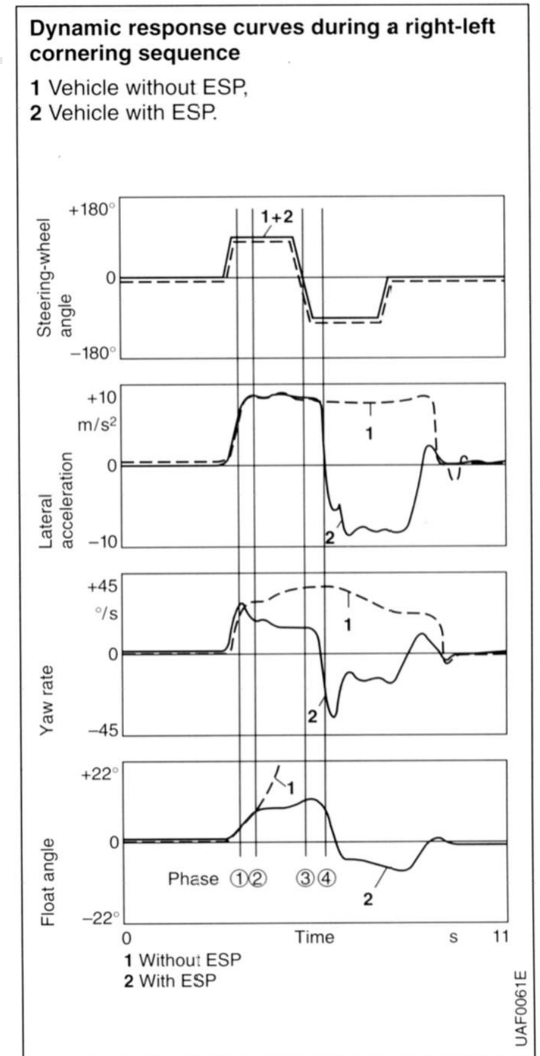
Vehicle Stability program

Example 1: right left cornering sequence

Road with a high friction grip μ = 1
The driver is not braking
V_{init} = 144 km/h

Bosch (1999)
Pages 207-208





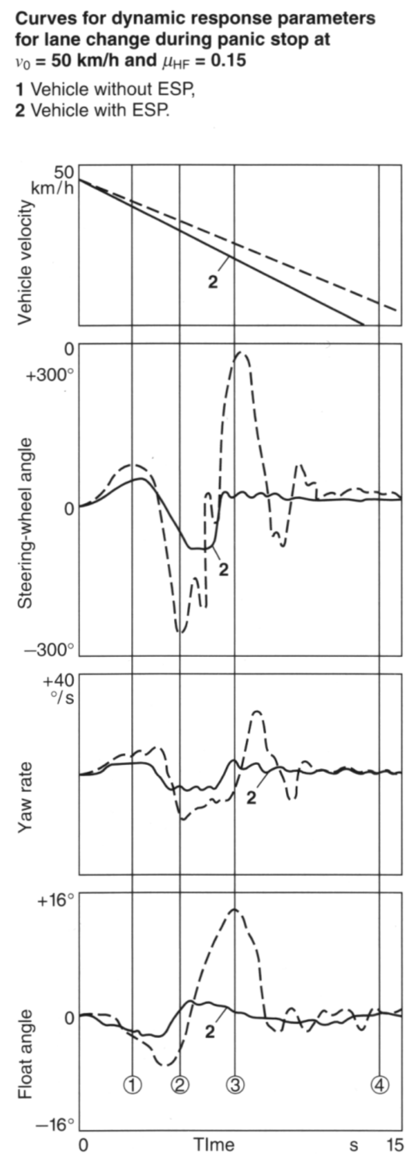
Introduction

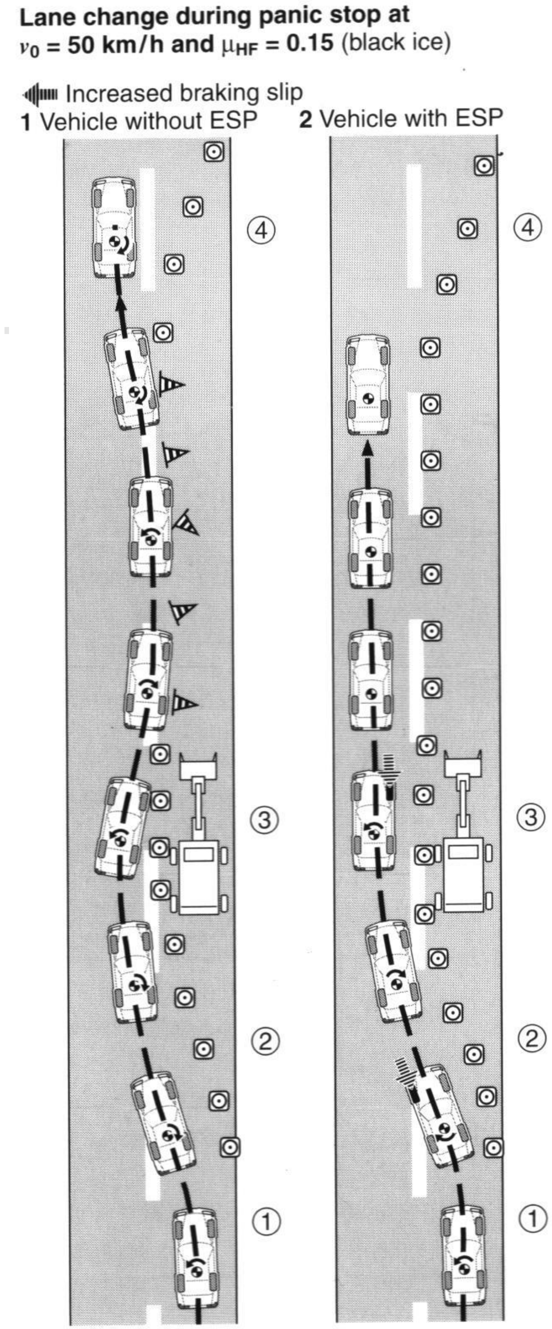
Example 2 : Lane change with panic stop

ABS versus ESP

Slippery road μ=0.15
V_{init} = 50 kph

Bosch (1999)
Pages 209-210



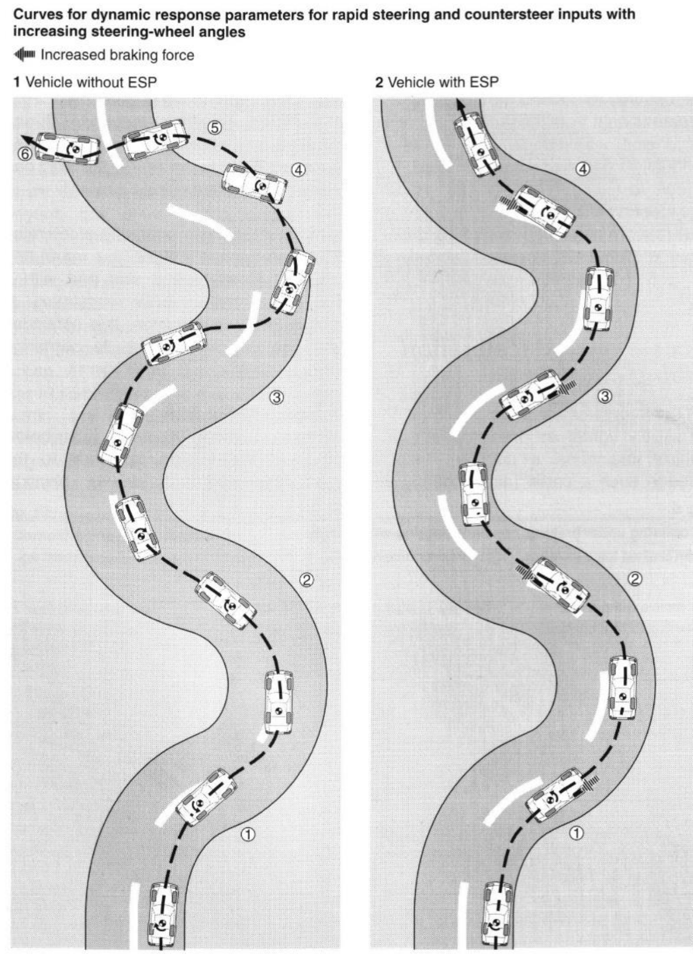


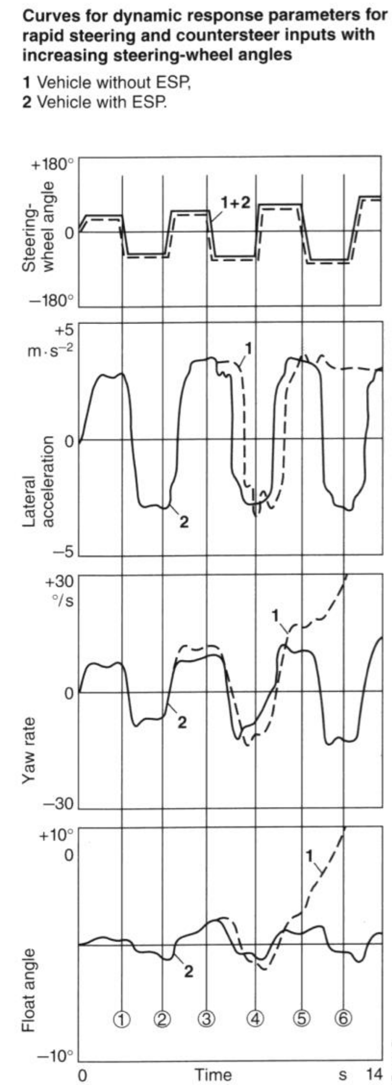
Introduction

Example 3 : Rapid steering and counter steering inputs

Road covered by snow
μ=0.45
No braking
V_{init} = 72 km/h

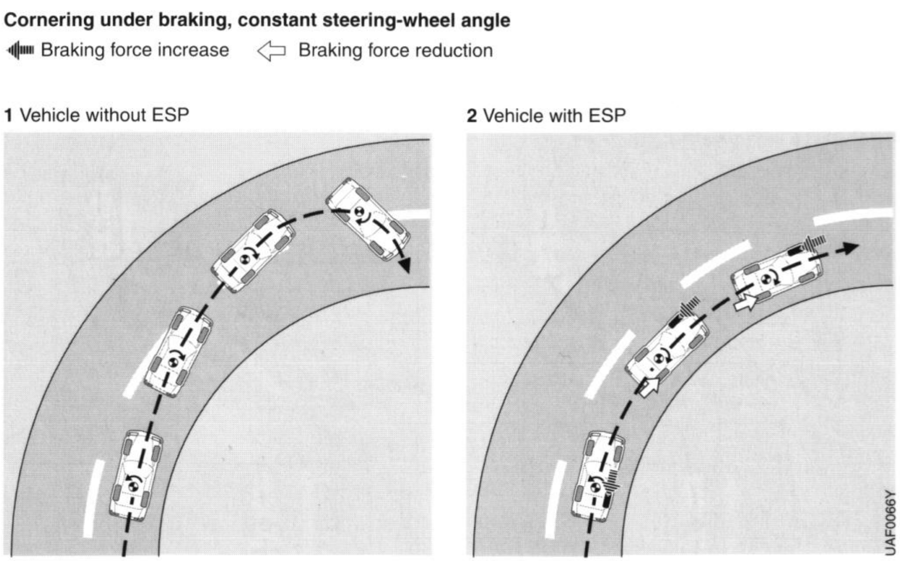
Bosch (1999)
Pages 210-212

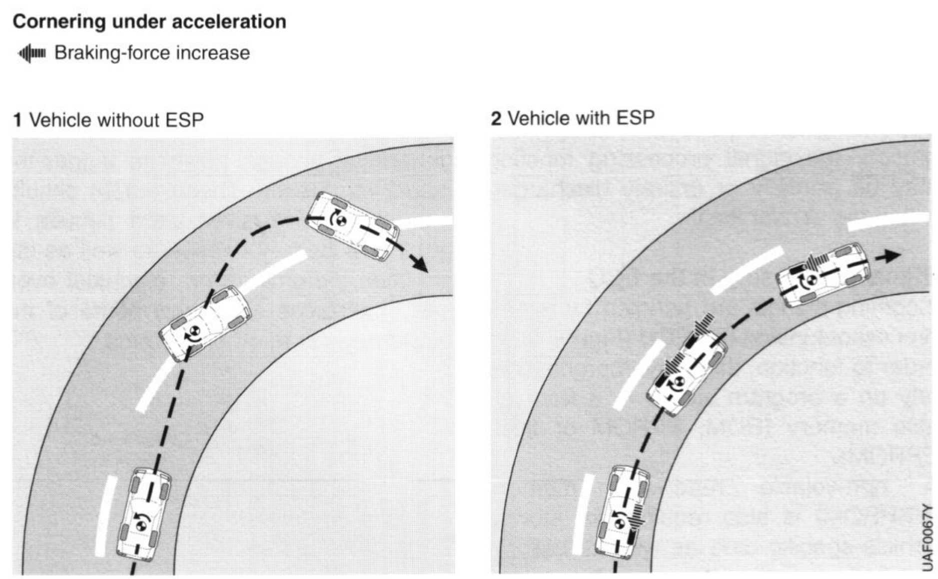




Introduction

Example 4 : Cornering under braking / accelerating





Curve wit a reducing radius (as in highway exit)
Constant speed

Bosch (1999)
Pages 212-213

Introduction

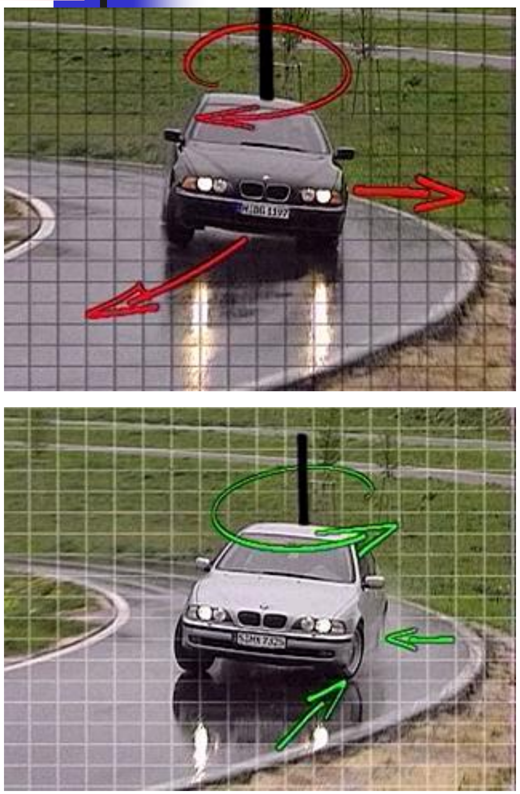
Example 4 : Cornering under braking / accelerating

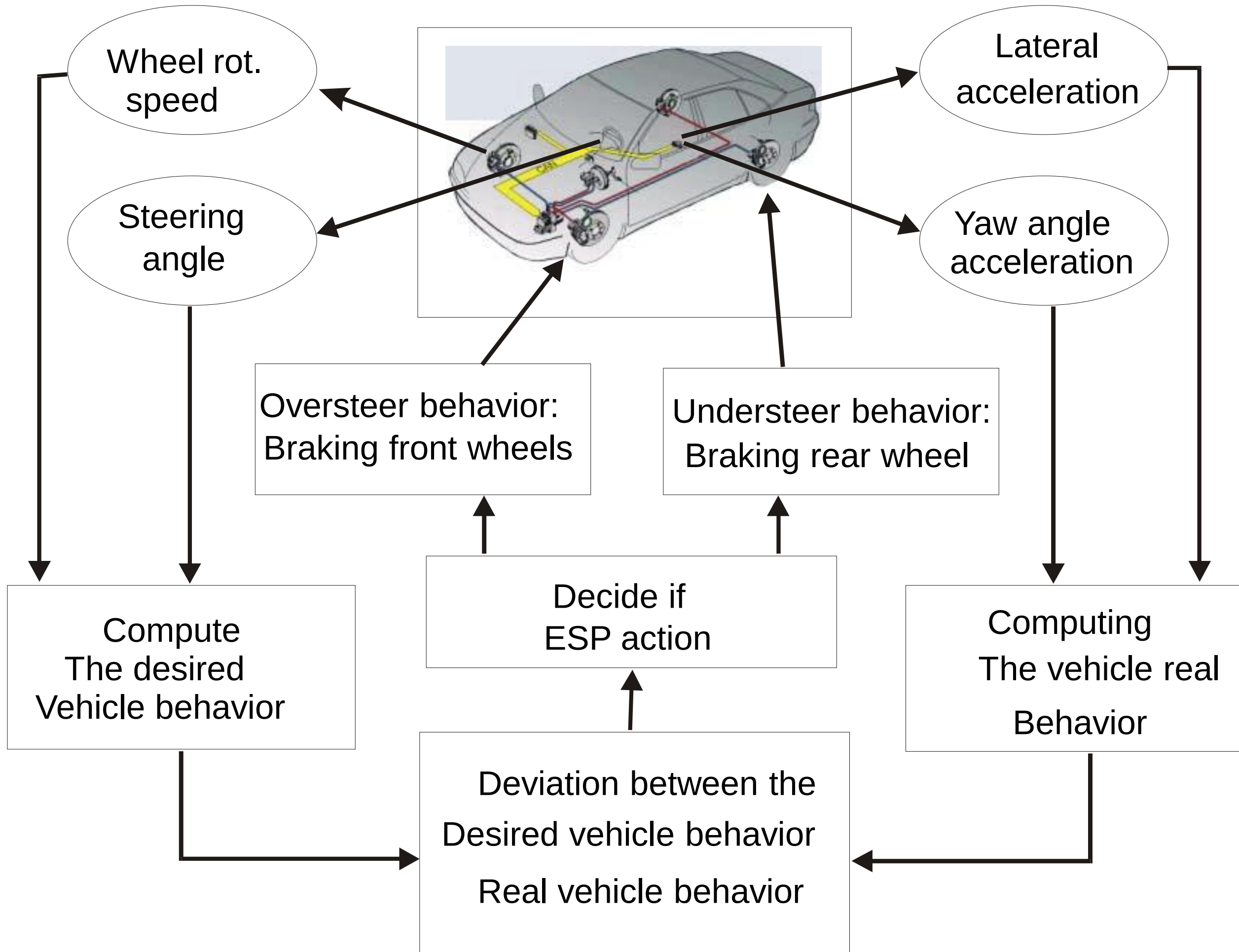
Circular test
Road with a high grip μ=1
Radius R=100m
Increasing speed up to the critical speed V=98 km/h

Above: Without ESP the vehicle breaks into a slide.
Below: ESP keeps the vehicle on track.

Bosch (1999)
Fig 11 Pages 213

Working principle of ESP



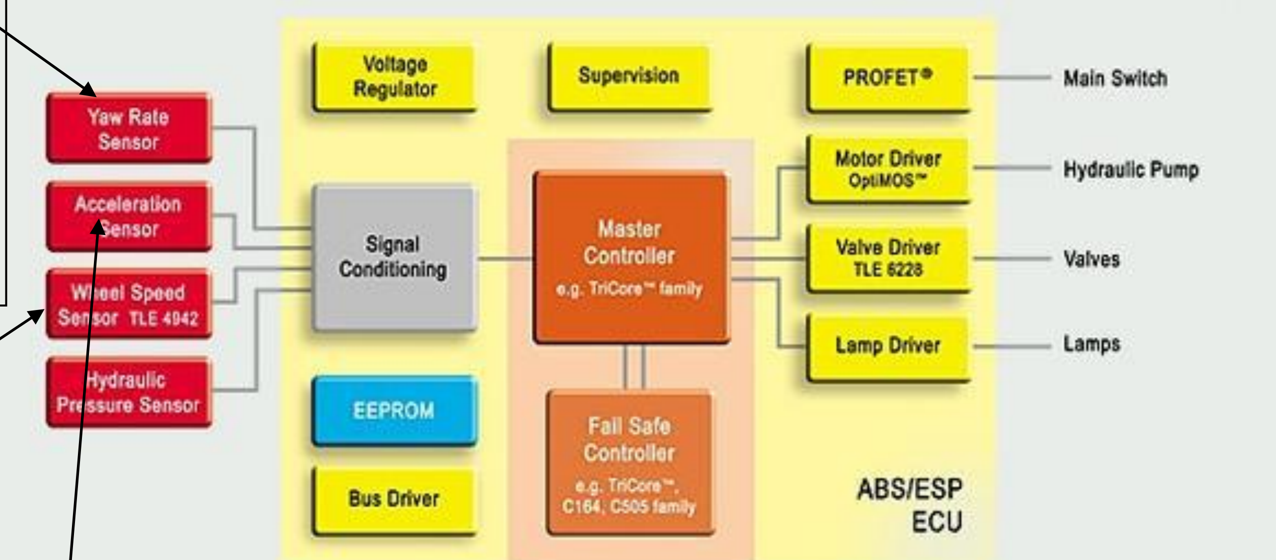


ESP = $(ABS+TCS)^2$

Instrumentation of the ESP

A micromechanical gyroscope (polySi surface micro machined MEMS) detects the rotations about the vehicle vertical axis

Miniaturized Sensors of the wheel rotation speed (based Hall effect)



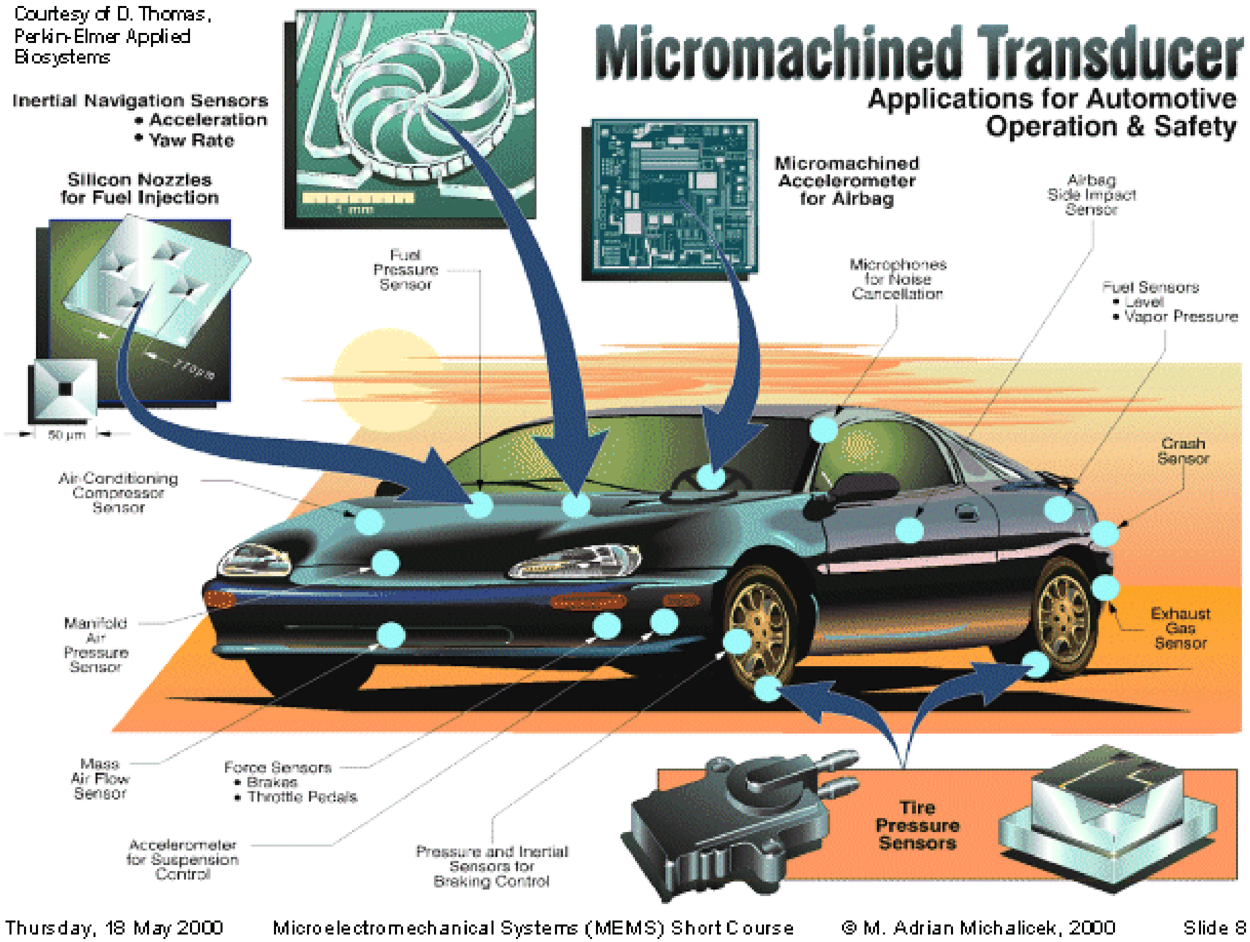
Field bus CAN bus

A highly sensitive MEMS accelerometer (polySi surface micromachined MEMS) Record the lateral acceleration

Steering wheel rotation measured by a contact less sensor

Source: Doc. Bosch

Microsystems & automobile



The Future of Safety: ADAS

- The future is Advanced Driver Assistance Systems or ADAS, are systems that aims to help the driver in its driving process. When designed with a safe Human-Machine Interface, it should increase car safety and more generally road safety.

Source www.conti-online.com

ADAS

- Examples of ADAS systems are:
  - In-vehicle navigation system with typically GPS and TMC for providing up-to-date traffic information
  - Adaptive cruise control (ACC)
  - Lane departure warning system
  - Lane change assistance
  - Collision avoidance system (Precrash system)
  - Night Vision
  - Adaptive light control
  - Pedestrian protection system
  - Traffic sign recognition
  - Blind spot detection
  - Driver drowsiness detection
  - Vehicular communication systems…

ADAS: examples

Emergency Brake Assist

The Emergency Brake Assist reacts when the driver does not realize the danger.

Adaptive Cruise Control:

ACC offers stress free driving with the traffic flow, while maintaining proper speed and distance to the traffic ahead.

Source conti www.conti-online.com

ADAS: examples

Lane Departure Warning /
Lane keeping System:
LDW / LKS provides the driver with warnings to protect him from unintentionally leaving the lane.

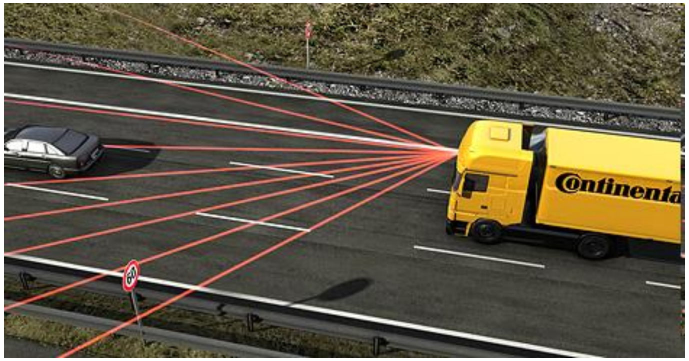
Blind Spot Detection:
BSD warns the driver when there are vehicles in the blind spot of the side-view mirror.

Source conti www.conti-online.com

ADAS: examples

Intelligent Headlamp Control:
Safer and less tiring driving through optimized vision at night.

Speed Limit Monitoring:
Speed Limit Monitoring ensures that the current speed limit is displayed for the driver on an ongoing basis.



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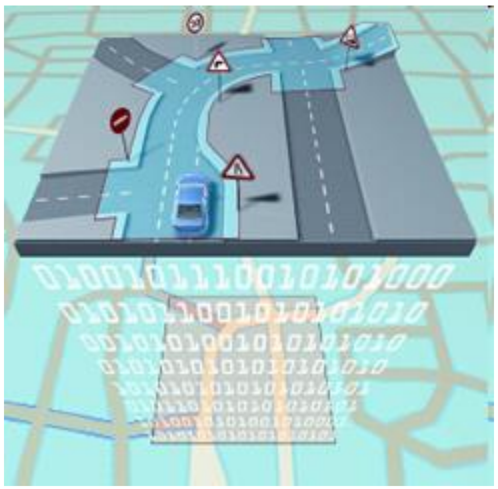
ADAS: examples

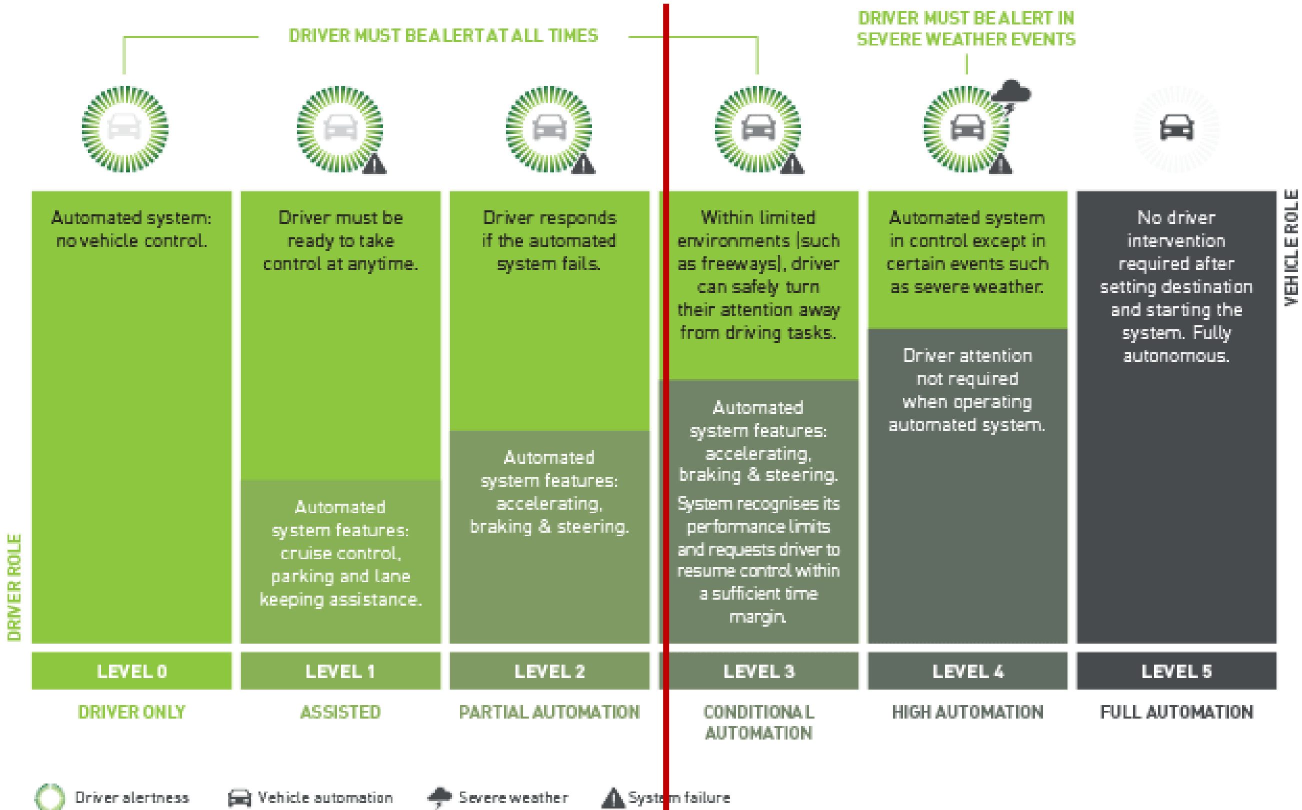


eHorizon:

The demands towards the performance of navigation systems grow. A fast, reliable and economical route calculation will be an essential quality characteristic.

Source conti www.conti-online.com

Autonomous vehicles



2020

Autonomous vehicles

- One key element of autonomous vehicles is the battery of sensors and in the fusion of the various information items

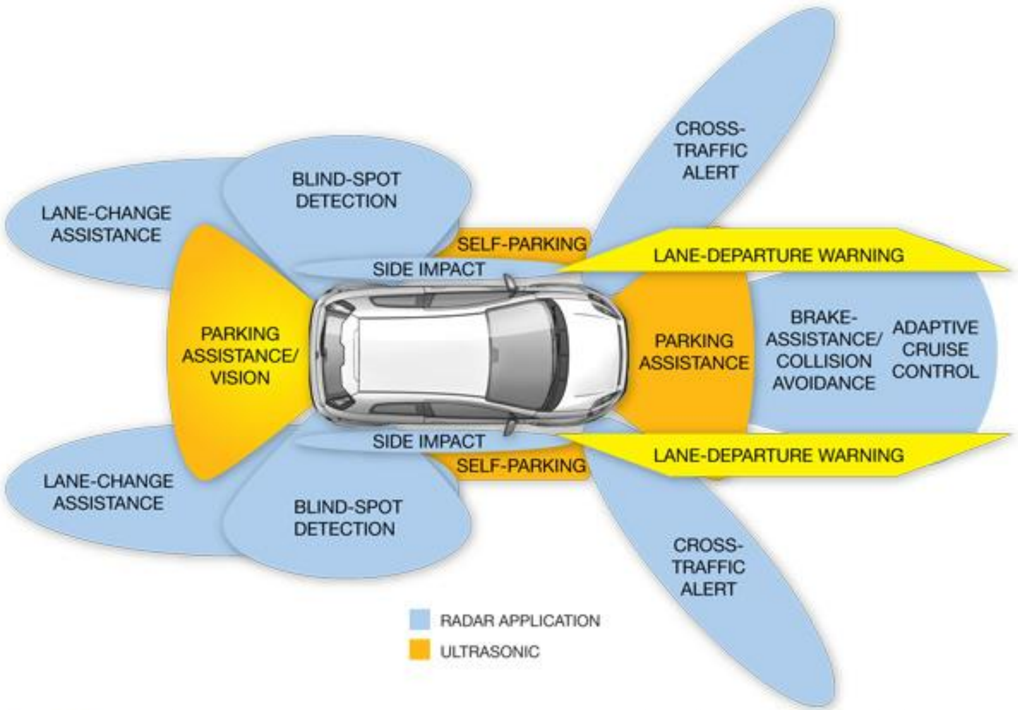
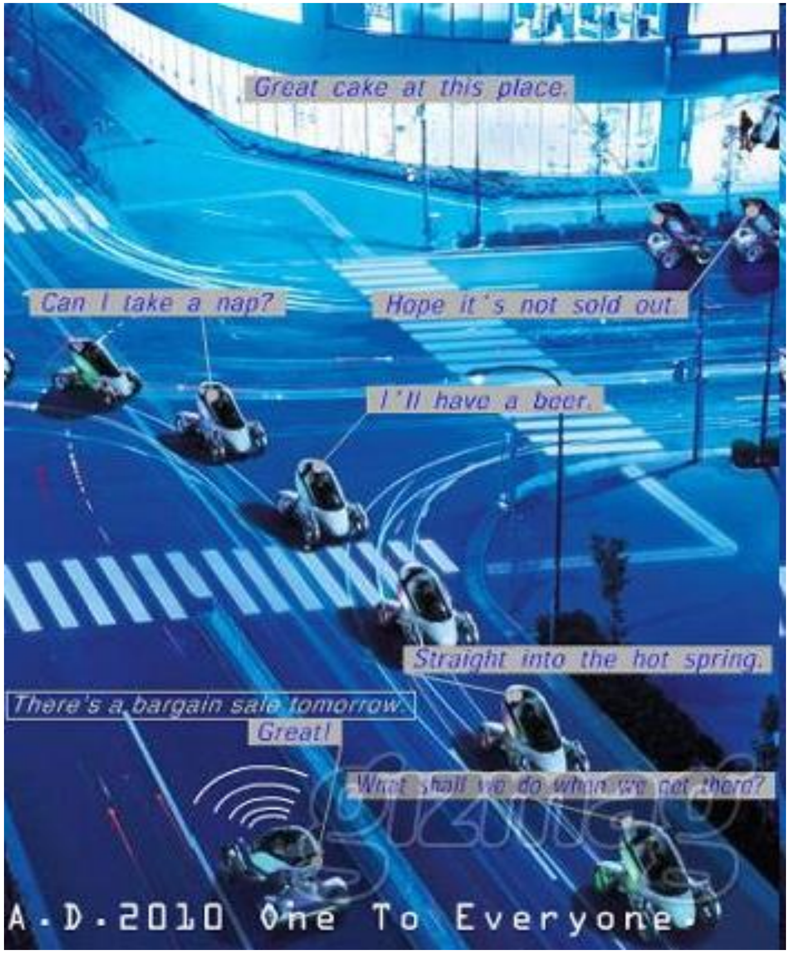


Figure 2 Several driver-assistance systems are currently using radar technology to provide blind-spot detection, parking assistance, collision avoidance, and other driver aids (courtesy Analog Devices).

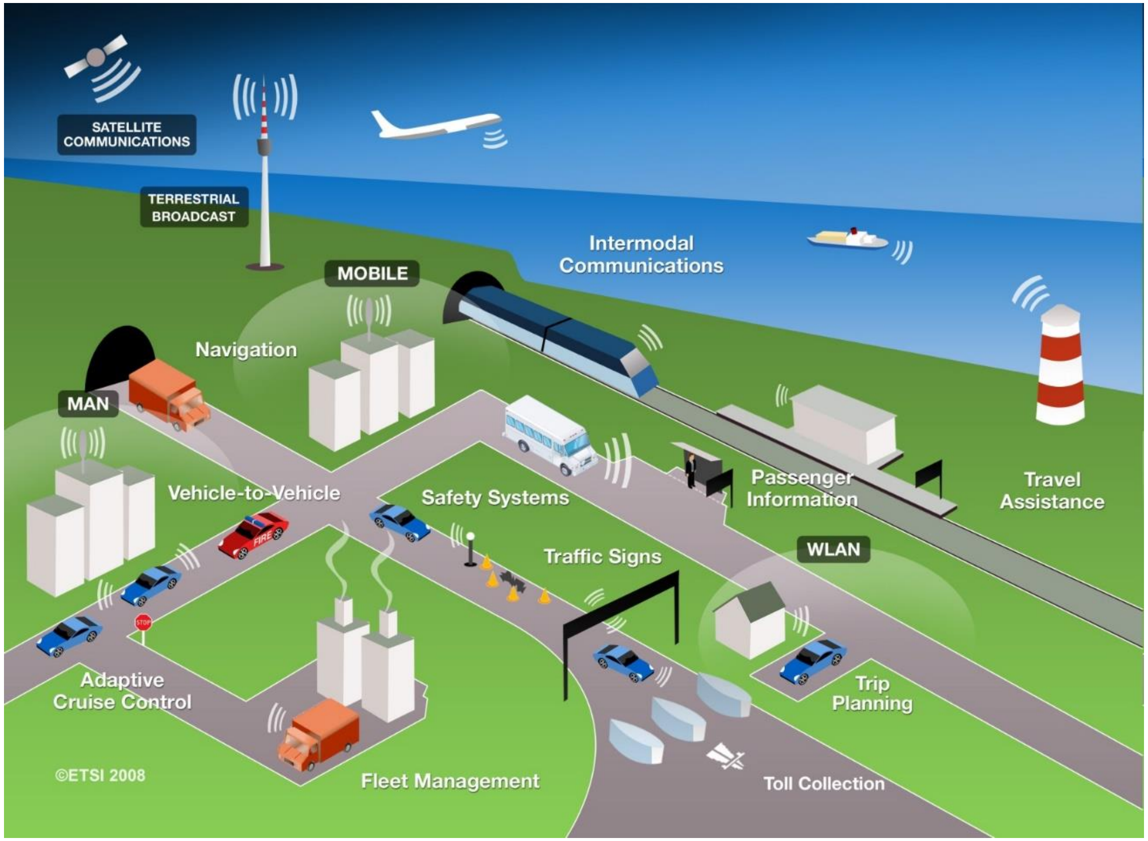
Autonomous vehicles

- Autonomous electric vehicles offers great opportunity for innovative solution in the urban driving


ADAS: Vehicular communication systems



INTELLIGENT TRANSPORTATION SYSTEMS



PART III : INFRASTRUCTURES

Infrastructure

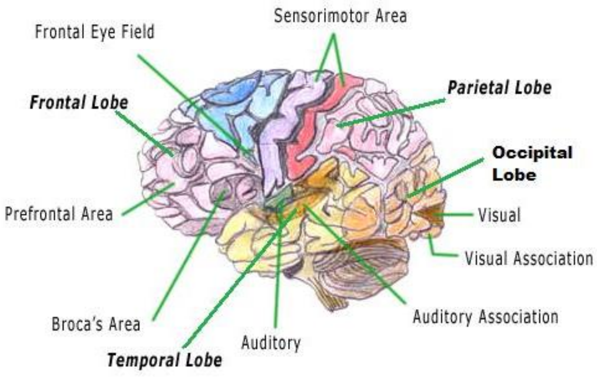
- In a car accident, there is three types of collisions that intervene sequentially:
  - 1/ Collision vehicle to obstacle: the vehicle is deformed and decelerated. The kinetic energy of the vehicle is dissipated.
  - 2/ Collision between the passenger and the vehicle or passenger to passenger. The passenger body can touch the steering wheel, the board, the windshield, etc.
  - 3/ Internal collisions of internal parts of body of the passenger. The damage of organs is due to internal collisions, high stresses in bones and tissues

Infrastructure

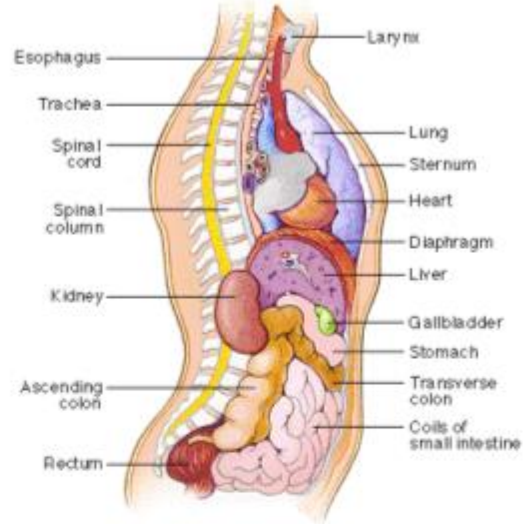
- Internal damages due to decelerations and shocks is the topics of biomechanics

- The resistance of body to deceleration and shocks are taken into account by empirical laws like Head Impact Criteria (HIC)

- However, we have little lever arms to reduce directly these damages



Lobes of the Brain
Sketch by Abhishake Sharma



Infrastructure

- The collisions between the passengers and the vehicle surfaces or between the passengers may lead to important body damages.
- The contact involves decelerations in body organs, efforts in bones and tissues
- To avoid or reduced the severity of these contacts, several systems have been tailored:
  - Seat belts
  - Seat belts pretensioners
  - Airbags

Infrastructure

- Collision vehicle to obstacle
  - The deformation of the compartment is dangerous so that the occupant can be prisoner of the vehicle.
  - The major parameters to mitigate the crash severity are

    - The energy absorption capability of the vehicle structure ➔ crushing zones to dissipate the energy

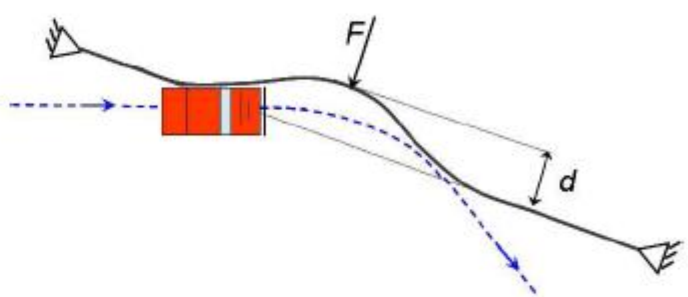
    - The resistance to deformation of the vehicle frame around the passengers to protect the occupants

Infrastructure

- In case of high severity crashes, the energy absorption is not sufficient, and the obstacle capacity to dissipate energy is essential to reduce the decelerations and the reduce the body injuries.
- This is the key role of restraint systems like: side rails, bumpers, etc.

Infrastructure

- Infrastructure specifications are ruled by EN1317 norm.
- Mainly the design of the safeguards is
  - To reduce the severity of the deceleration of the vehicle
  - To control the depth of the pocket in the crushed zone
  - To absorb as much as possible of the kinetic energy and to reduce the exit velocity of the vehicle.
- Design of safety infrastructure calls for a combined investigations including experimental testing and simulations as in vehicle crashworthiness



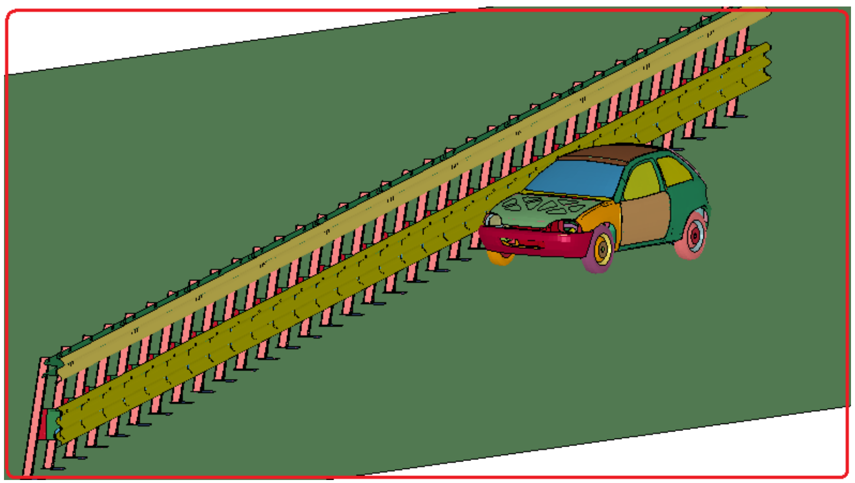
Infrastructure

- Crash test realized at LIER research center in France

http://www.lier.fr/Catalogue/Produit-Norme-europeenne-EN-1317-2.html

Infrastructure

- Simulations of crash test using fast dynamics software tools



Master Thesis by E. Michel, 2008

Master Thesis by X. Ernst, 2008