Case study – Cost-benefit analysis of vehicle systems

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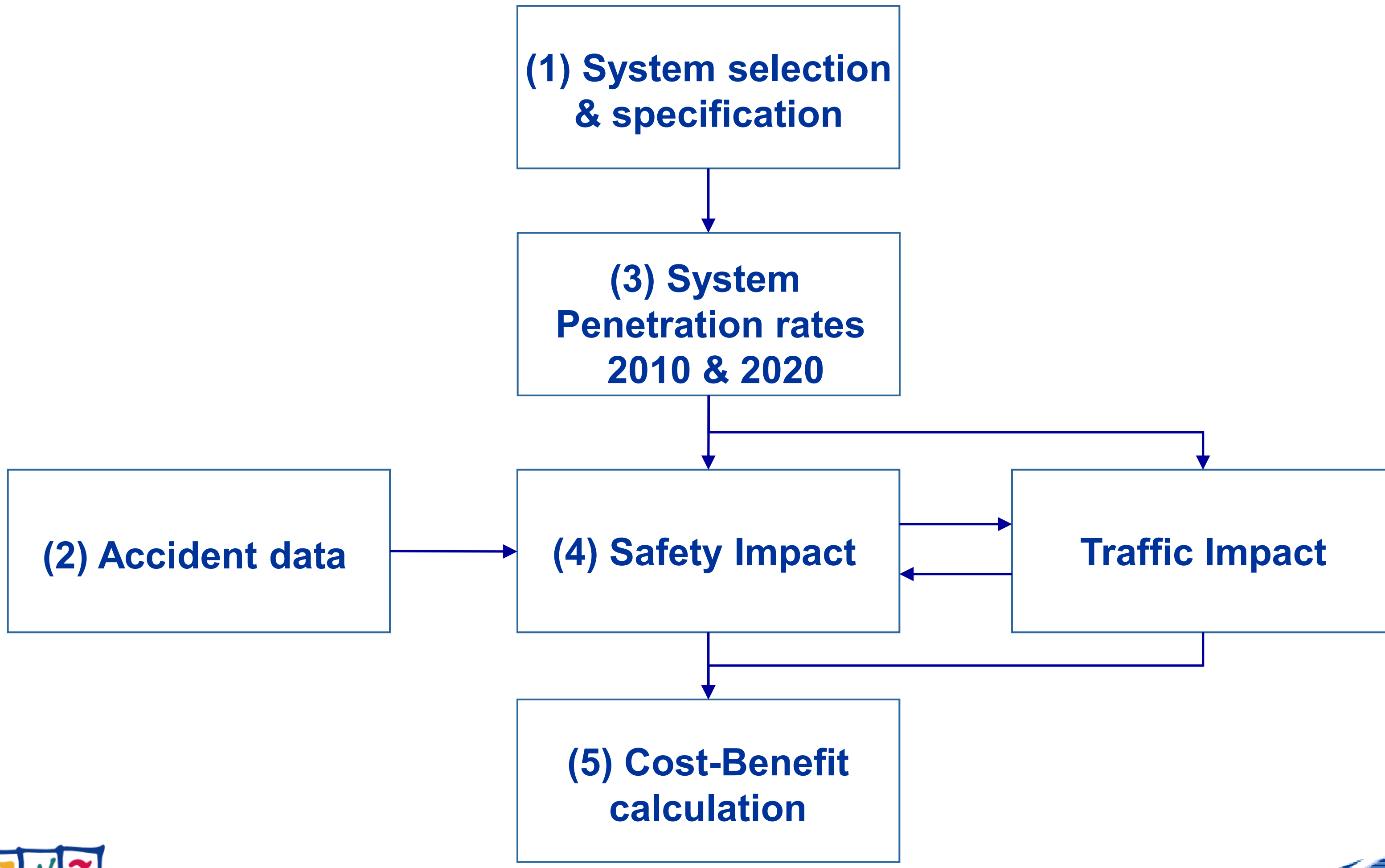
eIMPACT – Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe

- 6th Framework Project
- Coordinated by TNO
- Duration: January 2006 to December 2007
- 13 Partner:

eIMPACT: Objectives and key activities

- Identification of the most promising stand-alone and cooperative IVSS technologies
- Development of scenarios for 2010 and 2020
- Impact assessment of the IVSS for EU-25
  - Road safety impacts: avoided fatalities/ injuries
  - Direct traffic efficiency impact: changes in speeds, travel time gains and headways (→ Microsimulation)
  - Indirect traffic efficiency impacts: reduced congestion
- Identification of policies to enable the implementation of IVSS

Steps of Efficiency Assessment of IVSS in eIMPACT



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(1) System specification: Some categorization of vehicle systems (I)

- ADAS (Advanced driver assistant systems)
  - Driver comfort
  - Road safety
  - Road network capacity
- IVSS (Intelligent vehicle safety system) → eIMPACT
  - Crash avoidance
  - Injury prevention
  - Crash worthiness
- Stand-alone vs. cooperative systems
  - Cooperative system: exchange of road safety or traffic flow information between vehicles (V2V) or between vehicle and infrastructure (V2I or I2V)

(1) System specification: Cooperative systems (II)

Traffic
management

Vehicle-to-infrastruktur
WLAN (IEEE-Norm 802.11)

Vehicle-to-vehicle
WLAN (IEEE-Norm 802.11)

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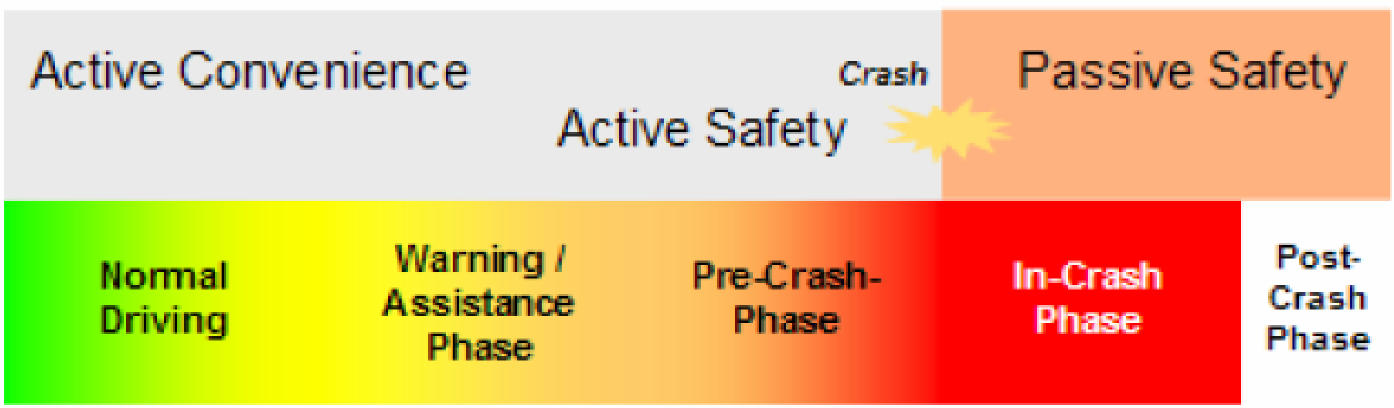
(1) System specification: Some categorization of vehicles systems (III)

- Systems correlation to a crash:
  - IVSS cover phases 2 to 5 → Safety focus
  - Normal driving situation: parking aid, navigation



Normal Driving	Warning / Assistance Phase	Pre-Crash-Phase	In-Crash Phase	Post-Crash Phase
Parking Assist	Lane departure warning, ACC	ESC, Emergency Braking	Airbag, Seatbelt	eCall

(1) Selected Intelligent vehicle safety systems (IVSS)

1. Electronic Stability Control (ESC)
2. Full Speed Range ACC (FSR)
3. Emergency Braking (EBR)
4. Pre-Crash Protection of Vulnerable Road Users (PCV)
5. Lane Change Assistant (Warning) (LCA)
6. Lane Keeping Support (LKS)
7. NightVisionWarn (NIW)
8. Driver Drowsiness Monitoring and Warning (DDM)
9. eCall (→ Cooperative system/ V2I)
10. Intersection Safety (INS) (→ Cooperative system/ I2V)
11. Wireless Local Danger Warning (→Cooperative system/ V2V)
12. SpeedAlert (SPE) (→ Cooperative system/ I2V)

(1) System specification: Emergency braking

Aim and use case

- Reduction of impact speed in case of immediate danger to increase passive safety and reduce accident consequences.
- Collision avoidance and collision mitigation in longitudinal traffic (rear-end collisions).

Function (three steps):

1. Optical and acoustical <u>warning</u>, if the approaching could lead to an accident.
2. <u>Autonomous partial braking</u>, if the distance is reduced further.
3. <u>Autonomous full braking</u>, if an accident appears inevitable.

Input is the distance and the relative speed to a leading vehicle.

(2) EU-25 Accident data base

Data requirements for safety impact assessment:

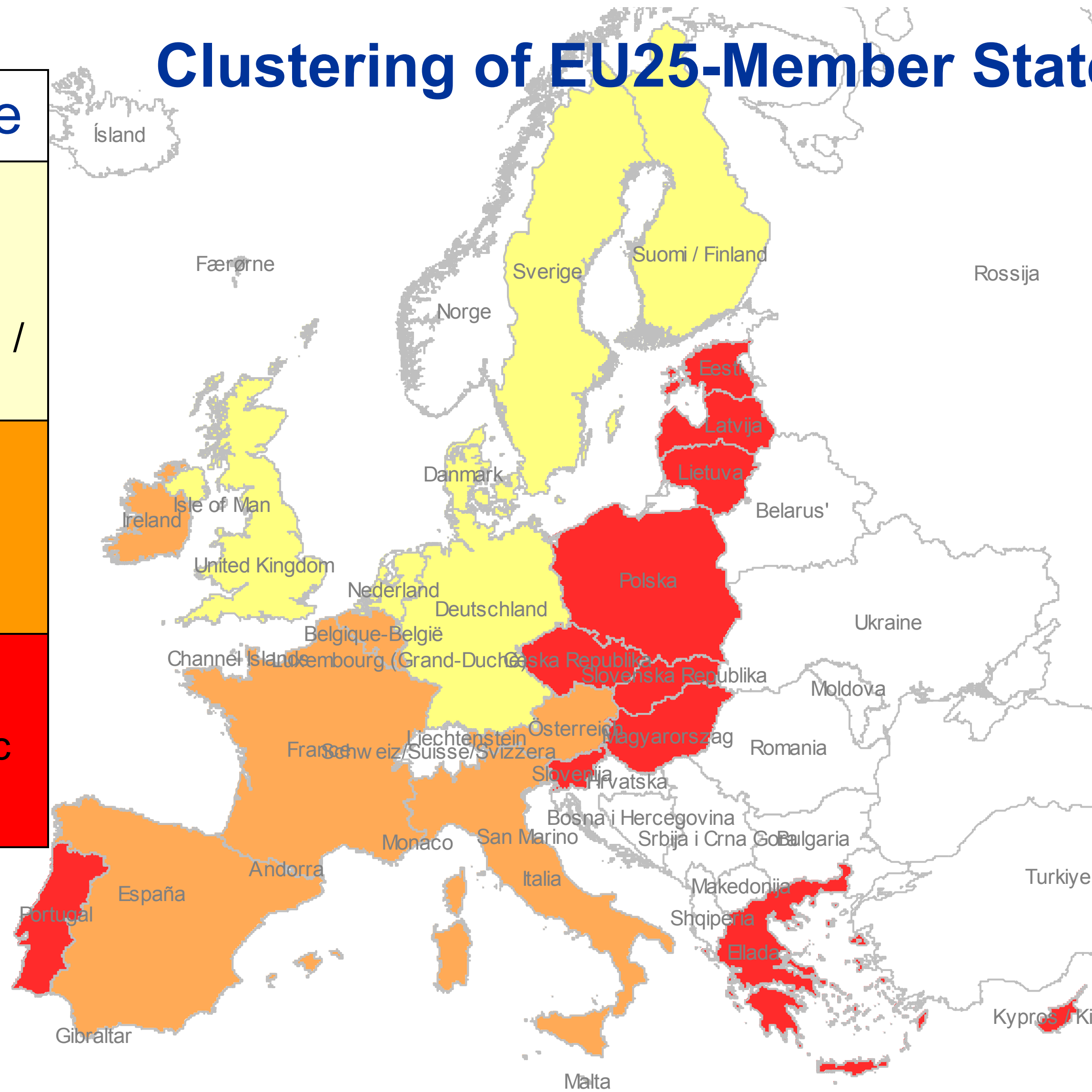
- Where does the IVSS work?
  - **Type of road**: urban, rural, motorway
  - **Type of vehicle**: car, truck
- In which situations does the IVSS work?
  - **Weather conditions**: normal weather (dry), bad weather (fog or mist, rain, snow, strong wind)
  - **Lighting conditions**: dark (darkness and no street lights), light (daylight, twilight, darkness and street lights)
- Which accident types are influenced by the IVSS?
  - **Collision types**
- How many accidents and causalities are addressed by IVSS?
  - **Number of accidents,**
  - **Number of fatalities, injuries**

(2) EU-25 Accident data base

- Problem: Limited provision of desired data by the CARE database
  - Database limited to EU-14 (EU-15 excluding Germany) plus Estonia, Hungary and Poland
  - Not all variables included in CARE (e.g. collision type variable)
  - Completeness of data not given for every country included in CARE
- National enquiry via TRACE Project
  - All desired variables included
  - Information on EU-25 as a whole
  - 3 Country-Clusters according to safety performance

Clustering of EU25-Member States

Representative
Cluster 1: - Germany - United Kingdom / Great Britain
Cluster 2: - France - Spain
Cluster 3: - Czech Republic - Greece



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(2) Accident data base: Scaled-up results of data enquiry (EU-25, year 2005)

	Fatalities	Injuries
Collision types		
1. Collision on the road with pedestrian	13 %	11 %
2. Collision on the road with all other obstacles	7 %	6 %
3. Collision beside the road with pedestrian or obstacle or other single vehicle accidents	22 %	13 %
4. Frontal collision	18 %	8 %
5. Side-by-side collision	2 %	5 %
6. Angle collision	15 %	25 %
7. Rear collision	5 %	13 %
8. Other accidents with two vehicles	3 %	6 %
9. All other collisions	14 %	13 %

(2) EU-25 Accident data base: Forecast for 2010 and 2020

- Trend extrapolation based on exponential regression of accident data for the period 1991 to 2005

	2005	2010	2020
Fatalities	41305	33,895	20,791
Injuries	1,489,567	1,409,415	873,695

(3) Market data: Penetration rates and mileage share

- Market introduction after 2010
- 2 Scenarios:
  - Low scenario ("Business as usual"): Development follows "normal" path of diffusion by starting in luxury car segment and then cascading down to lower car segments.
  - High scenario ("Policy options"): Financial incentives to support the market take-up of the systems are given (e.g. tax subsides, insurance premium rebates).
- Converting fleet penetration rates to **mileage driven** by equipped vehicles because new vehicles usually make more km's than old vehicles.

(3) Market data: Penetration rates and mileage share

Expert estimation:

	2010		2020	
Scenarios	Low	High	Low	High
Fleet penetration	0 %	0 %	3,6 %	8,2 %
Share of vehicle kilometers	0 %	0 %	4,5 %	9,9 %

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Assessing the Impacts of
Intelligent Vehicle Safety Systems

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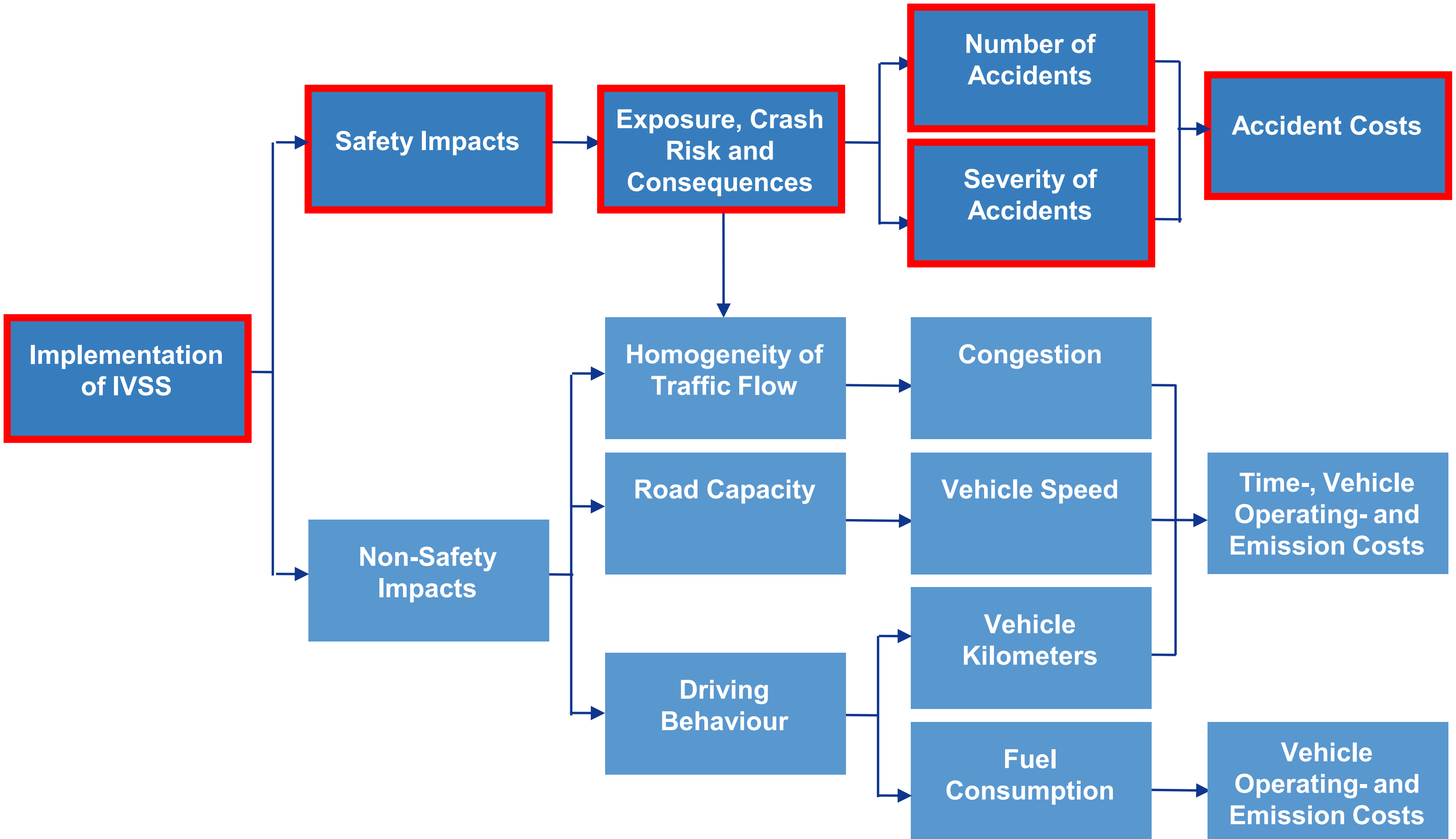
(4) Safety impact: General impact model of IVSS



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(4) Safety impact: Emergency braking (I)

- Identification of direct and indirect effects of IVSS on road safety in a systematic way by “safety mechanisms”:
  - **Direct in-car modification of the driving task**: Giving information, advice and assistance or taking over part of the task
  - **Behavioral adaptation/** compensation: Less concentration on the driving task and/ or more risky driving with more speed and less headway; was assumed to be very limited as EBR intervenes only in extremely dangerous situations and later than the braking of a normal driver.

(4) Safety impact: Emergency braking (II)

- Technical performance:
  - Radar system to detect imminent crashes is best for moving objects which addresses rear-end-accidents.
  - Accidents with fixed objects are also addressed, but detection is more difficult as the system has to distinguish more accurately between vehicles and other objects.
  - Detection of pedestrians was not considered.

(4) Safety impact: Emergency braking (III)

- Estimated safety effects on fatalities and injuries for different collision types (2)

	Fatalities	Injuries
Total effect (100%-penetration)	**-7 %**	**- 7 %**
1. Collision on the road with pedestrian	0 %	0 %
2. Collision on the road with all other obstacles	-24 %	-20 %
3. Collision beside the road with pedestrian or obstacle or other single vehicle accidents	-12 %	-10 %
4. Frontal collision	0 %	0 %
5. Side-by-side collision	0 %	0 %
6. Angle collision	-6 %	-5 %
7. Rear collision	-30 %	-25 %
8. Other accidents with two vehicles	-12 %	-10 %

(5) Cost-benefit assessment: Emergency braking

Cost-unit rates*

- Safety effects: Avoided fatalities and injuries
  - The cost-unit rates are based on the year 2003 and scaled up to year 2010 and 2020 (Growth rate of GDP: 3 %)
  - All values in the report are expressed in year 2008 prices by using an inflation rate of 2 %.
- Indirect traffic effects: Time gains by avoided accidents (= avoided congestion costs)

*eIMPACT, D6, 2008, rounded values

	2020	
	Fatalities (EUR)	**Injuries (EUR)**
Per fatality/ injury	1,600,000	63.000
Per accident with fatality/ injury	18,000	5,000
Average congestion costs per accident with fatality/ injury	15.500	5.000
Sum	1,633,500	73.000

(5) Cost-benefit assessment: Emergency braking

- Calculation scheme for safety benefits (low/ high scenario):

  Safety effect (7 %)

  x Forecasted number of fatalities/ injuries in 2020

  = safety impact (100-% penetration rate) **= 1,455 / 63,780**

  x Share of driven mileage (4.5 % / 9.9 %)

  x Cost-unit rate avoided fatality/ injury/ congestion

  = 425 Mio. EUR / 1108 Mio. EUR

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(5) Cost-benefit assessment: Emergency braking

- Safety benefits*

"Corrected" safety effects = Safety effect x Mileage share

	2010		2020	
	low	high	low	high
percentage				
fatalities			0.3	0.9
injuries			0.5	1.3
absolute numbers				
fatalities			72	193
injuries			4,241	10,925
monetised benefit [mill. Euro]				
fatalities			117.0	313.7
injuries			288.0	741.8
total			**405.0**	**1,055.5**

Table 26: Safety effects of Emergency Braking

*eIMPACT, D6, 2008, p. 49

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(5) Cost-benefit assessment: Emergency braking

System costs (1)

- Components: Mid-wave radar, Warning module, braking actuation, Vehicle trajectory estimation, Driver intention estimation
- Cost estimation by eIMPACT expert group: Bosch GmbH, Daimler AG, BMW AG, University of Cologne
- Assumptions:
  - IVSS is used over the complete lifetime of the vehicle.
  - Average economic lifetime of a vehicle in EU25: 12 years
  - Discount factor: 3 %

(5) Cost-benefit assessment: Emergency braking

System costs (2)

- Calculation of yearly system costs in 2020 using Annuity Rate (n = 12, d = 0,03):

$$AR = \frac{d * (1+d)^n}{(1+d)^n - 1} = \frac{0.03 * 1.03^{12}}{1.03^{12} - 1} = 0.10046$$

- System costs: 107 EUR in total, 10.7 EUR/ p.a. (= 107 EUR x 0.1)
- Total fleet costs:

Scenario	Penetration rate	System costs p.a.	Vehicle Fleet (2020)*	Total costs
Low	3,6 %	10.7 EUR	307 Mio.	118 Mio. EUR
High	8,2 %	10.7 EUR	307 Mio.	269 Mio. EUR

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*ProgTrans European Transportation Report 2007/2008

(5) Benefit-cost ratios (low/ high scenario)

- Calculation scheme for system costs:

  System costs per vehicle: 10.7 EUR

  x Penetration rate (3,6 % / 8,2 %)

  x Forecasted fleet: 307 Mio.

  = 118 Mio. EUR / 270 Mio. EUR

(5) Benefit-cost ratios for Emergency braking

Safety benefits
(low/ high scenario)
= 425 Mio. EUR /
1,108 Mio. EUR

Fleet system costs
(low/ high scenario)
= 118 Mio. EUR /
270 Mio. EUR

Benefit-cost ratio =
Benefits/system costs
= 3.6 / 4.1

(5) Cost-effectiveness ratio for Emergency braking

Fatalities avoided
(low/ high scenario)
= 72 / 193

Fleet system costs
(low/ high scenario)
**= 118 Mio. EUR /
270 Mio. EUR**

Cost-effectiveness
ratio =
**1.6 Mio. EUR /
1.4 Mio. EUR**

$$\leq 1.6\ \text{Mio. EUR}$$

$$= \text{Cost-unit rate fatality}$$

Final remarks

- Benefit cost ratios (BCR) of 3.6 and 4.1 are labeled as excellent. The system is the best considered system in 2020.
- Sensitivity analysis done to check stability of results wrt:
  - Discount rate (3 % → 8 %)
  - Lifetime (12 → 16 years)
  - Pessimistic/ optimistic safety effect (3 %, 9 %)
  - Accident trend → highest sensitivity

  → EBR remains in all cases social profitable: BCR > 1