Cost-benefit assessment and prioritisation of vehicle safety technologies

Framework Contract TREN/A1/56-2004
Lot 2: Economic assistance activities

FINAL REPORT

Our ref: TREN-ECON2-002

Client: European Commission - DG TREN

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European Commission Directorate General Energy and Transport

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January 2006

Report no.	02
Issue no.	03
Date of issue	19 January 2006
Prepared	TOD, MKH, MTB
Checked	MTB
Approved	MTB

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Executive summary

In 2001, 50,379 people lost their lives[1] and millions were injured as a result of road accidents in Europe.

There are many possible actions which can be taken to improve road safety, thus reducing the number of fatalities and injuries. These include improving the enforcement of existing rules, improving infrastructure, improving driver behaviour and introducing safety technologies in vehicles.

The objective of this study is to assess the introduction of 21 vehicle safety technologies based on existing literature, data and knowledge.

By means of an economic cost-benefit analysis of each of these technologies, a priority list has been established to inform and guide decision-makers on the most beneficial steps to take in the future to reduce the number of accidents and/or the severity of accidents in EU-25.

The assessment of each of the vehicle technologies is based on a common approach to ensure that the technologies are evaluated at equal premises.

Approach

The economic cost-benefit assessment compares the costs of installing the relevant technology in all relevant new vehicles with the benefits for society of doing so in terms of reduced numbers of fatalities, severe injuries and slight injuries.

The estimation of the costs of the safety systems is based on information collected from existing literature.

The estimated effects on the number of fatalities, severe injuries and slight injuries are based on:

- Existing studies
- Accident data (primarily the CARE database)

[1] Preliminary statistics indicate that the number of injury accidents and casualties in 2002-2004 are lower.

– Estimates of the effectiveness of the technology in terms of reducing the risk of collision and/or the severity of injuries in case an accident occurs

– A scenario for implementation (market penetration in the Do-something scenario and the Do-nothing scenario)

The valuation of accident costs is based on the standard uniform accident costs presented in the table below.

Table 0-1 Applied unit values - Accident (€ per fatality/injury)

Category	€ per fatality/injury
Fatality	1,018,200
Severe injury	143,100
Slight injury	23,100

The applied unit values have a large impact on the estimated benefit/cost-ratio. If higher values are used the benefit/cost-ratio will increase, and vice versa for lower unit values. The level of the applied unit values does not affect the relative ranking of the technologies.

Reservations

Economic cost-benefit analysis is the preferred method for evaluating the performance of vehicle safety technologies. The results of an economic cost-benefit assessment can however not stand alone, as not all effects are included in the assessment, and as the quantification and valuation of effects are uncertain. Factors such as affordability, obstacles to implementation or the competitiveness of the European car industry have to be investigated further in the future process.

Furthermore, it should be noted that the results presented here are based on a stand-alone implementation of the technologies, and that for several of the technologies the information on costs and effectiveness is relatively sparse.

Main results

The results of the economic cost-benefit analysis are summarised in the table below.

The benefit/cost-ratio is estimated for 13 of the 21 technologies. For 4 additional technologies the break-even unit costs have been estimated, as no solid cost estimates were available in the existing literature. If actual unit costs are lower than the estimated break-even unit costs, the technology can be considered as cost-effective. For 4 of the technologies virtually no cost-benefit data was available.

Table 0-2 Summary - main results of economic cost-benefit assessment (Benefit/cost-ratio, BCR)

Category - according to economic cost-effectiveness	Technology	Benefit/cost-ratio (BCR) Central estimate	Comment
1. Cost-effective (BCR>3)	▪ Seat belt reminders ▪ Event or accident data recorders ▪ Electronic stability control (ESC) ▪ Retro-fitting of blind spot mirrors ▪ Intelligent speed adaptation (ISA) ▪ Alcohol ignition interlocks	7.6-8.2 7.1 3.8 3.8 3.3 3.1	Depending on system
2. Most likely cost-effective (1<BCR<3)	▪ Conspicuity marking ▪ Under-run protection ▪ Daytime running lights ▪ Lane departure warning	2.5 2.4 1.8 1.7	
3. Most likely not cost-effective (0.25<BCR<1)	▪ Adaptive cruise control (ACC)	0.4	
4. Not cost-effective (BCR<0.25)	▪ Tyre pressure monitoring systems	0.04	
Difficult to categorise	▪ eCall	0.4-2.0	Depending on cost estimate
Break-even cost calculated	▪ Collision warning system ▪ Fatigue detectors ▪ Improved vehicle compatibility ▪ Brake assistant systems	Break-even costs = €1,200/vehicle Break-even costs = €710/vehicle Break-even costs = €285/vehicle Break-even costs = €460/vehicle	
Virtually no cost-benefit data	▪ Soft nose on trucks ▪ Improved seats and headrests ▪ Brake measurement devices ▪ Universal anchorage systems (ISOFIX)		

It can be concluded that:

- A large number of the technologies under consideration appear to be either *cost-effective* (benefit/cost-ratio>3) or *most likely cost-effective* (benefit/cost-ratio between 1 and 3)
- *Seat belt reminders* and *event or accident data recorders* appear to be the most cost-effective vehicle technologies, but it also appears that *electronic*

stability control (ESC), retro-fitting of blind spot mirrors, intelligent speed adaptation (ISA) and *alcohol ignition interlocks* are very promising.

- The three vehicle technologies which directly address accidents involving HGV; *retro-fitting of blind spot mirrors, conspicuity marking of HGV* and *under-run protection* are considered to be *cost-effective* or *most likely cost-effective*. The cost-effectiveness of retro-fitting of blind spot mirrors depends crucially on the year of implementation. The sooner the initiative is implemented the more cost-effective.
- It has proven difficult to provide solid evidence on the cost-effectiveness of the in-vehicle emergency system *eCall* to due a lack of solid estimates of the total cost of the system.
- *Adaptive cruise control (ACC)* and *tyre pressure monitoring systems* appear to be less cost-effective measures to improve road safety.
- For 4 technologies, no benefit/cost-ratio has been estimated due to a lack of solid cost estimates. Some of these systems seem to be effective, but further research is needed to determine their cost-effectiveness.
- For the final 4 vehicle technologies, virtually no cost-benefit data is available. Due to the nature of the technologies it could prove difficult to assess the cost-effectiveness of the systems, even if further research is conducted. This does however not necessarily signify that the technologies are not cost-effective measures for improving the safety on the European roads.

The robustness of the results has been analysed through a number of sensitivity analyses for each of the technologies. The fact that a large number of the technologies under consideration appear to be either *cost-effective* or *most likely cost-effective* is robust to the assumptions made.

Preamble

This study was initiated by the Directorate-General Energy and Transport of the European Commission (DG TREN) in August 2005.

The study was carried out by the contractor, COWI, by a team led by Mette Bøgelund. The team also comprised Thomas Odgaard (CBA expert), Morten Klintø Hansen (safety expert) and Henrik Grell (safety/traffic expert).

We would like to thank a number of experts and stakeholders for having contributed information and comments to the study.

The views and opinions expressed in the study are those of the team of experts who conducted the study and do not necessarily represent the views and opinions of the European Commission.

1 Introduction

1.1 Context

In 2001 50,379 people lost their lives[2] and millions were injured as a result of road accidents in Europe.

It is the objective of the Commission, as documented in the DG TREN transport White Paper[3], to reduce the number of road fatalities by 50% in 2010.

There are many possible actions which can be taken to improve road safety. These include improving the enforcement of existing rules, improving infrastructure, improving driver behaviour and introducing safety technologies in vehicles.

1.2 Objectives

The objective of this study is to assess the introduction of 21 vehicle safety technologies based on existing literature, data and knowledge.

By means of an economic cost-benefit analysis of each of these technologies, a priority list has been established to inform and guide decision-makers on the most beneficial steps to take in the future to reduce the number of accidents and/or the severity of accidents in EU-25.

The assessment of each of the vehicle technologies is based on a common approach to ensure that the technologies are evaluated at equal premises.

1.3 Structure of the report

A summary of the findings is presented chapter 2, including the prioritised list of technologies.

For readers interested in more details the general framework for the assessment of vehicle technologies is outlined in chapter 3. The detailed approach to the

[2] Preliminary statistics indicate that the number of injury accidents and casualties in 2002-2004 are lower.

[3] European Commission (2001)

safety assessment is described in chapter 4, while the approach to the economic cost-benefit analysis is described in detail in chapter 5.

Chapters 6-22 present the assessment of costs and benefits for each of the vehicle technologies for which the relevant data on at least benefits is available. The structure of these chapters is as follows:

- x.1 *Definition of technology*: Information on the technology under consideration and how it is intended to work.
- x.2 *Accidents - Do-nothing scenario*: Defines the type and number of accidents which the technology can help to mitigate.
- x.3 *Scenario for implementation*: The scenario for the implementation of the technology is outlined (e.g. development in market penetration in the Do-nothing and Do-something scenario).
- x.4 *Cost assessment*: The cost of implementing the technology is assessed on the basis of the scenario for implementation.
- x.5 *Safety impacts*: The effectiveness of the technology is assessed in terms of reducing the risk of collision and/or the severity of injuries in case an accident occurs.
- x.6 *Accidents - Do-something scenario*: The reduction in the number of fatalities, severe injuries and slight injuries is assessed on the basis of the number of relevant accidents, the scenario for implementation and the effectiveness of the technology.
- x.7 *Cost-benefit assessment*: Finally, the economic cost-benefit assessment is presented together with an evaluation of the robustness of the results to the assumptions made.

Finally, chapter 23 summarises the information available on the 4 technologies for which virtually no cost-benefit data is available.

2 Summary and conclusions

The approach to and results of the economic cost-benefit assessment are summarised in this chapter.

2.1 Background

In 2002, close to 50,000 people lost their lives and millions were injured as a result of road accidents in Europe (see Table 2-1).

The total annual costs for society are - on the basis of the valuation of accidents presented in the table below - estimated at € 229 billion per year.

Table 2-1 Number of fatalities/injuries per year, unit costs per accident and costs to society per year - EU-25 (based on data for 2002)

	No.	€ per fatality/injury	Costs to society (billion €)
Fatalities	49,686	1,018,200	51
Severe injuries	480,043	143,100	69
Slight injuries	4,730,451	23,100	109
Total	-	-	229

Source: CARE, adjusted for non-reported accidents

Note: The number of fatalities/injuries is projected to decline over the coming years even if nothing is done to promote the use of the technologies under consideration.

2.2 Technologies

The objective of this study is to assess the introduction of 21 vehicle safety technologies based on existing literature, data and knowledge. A short description of each of the technologies under consideration is provided in the table below.

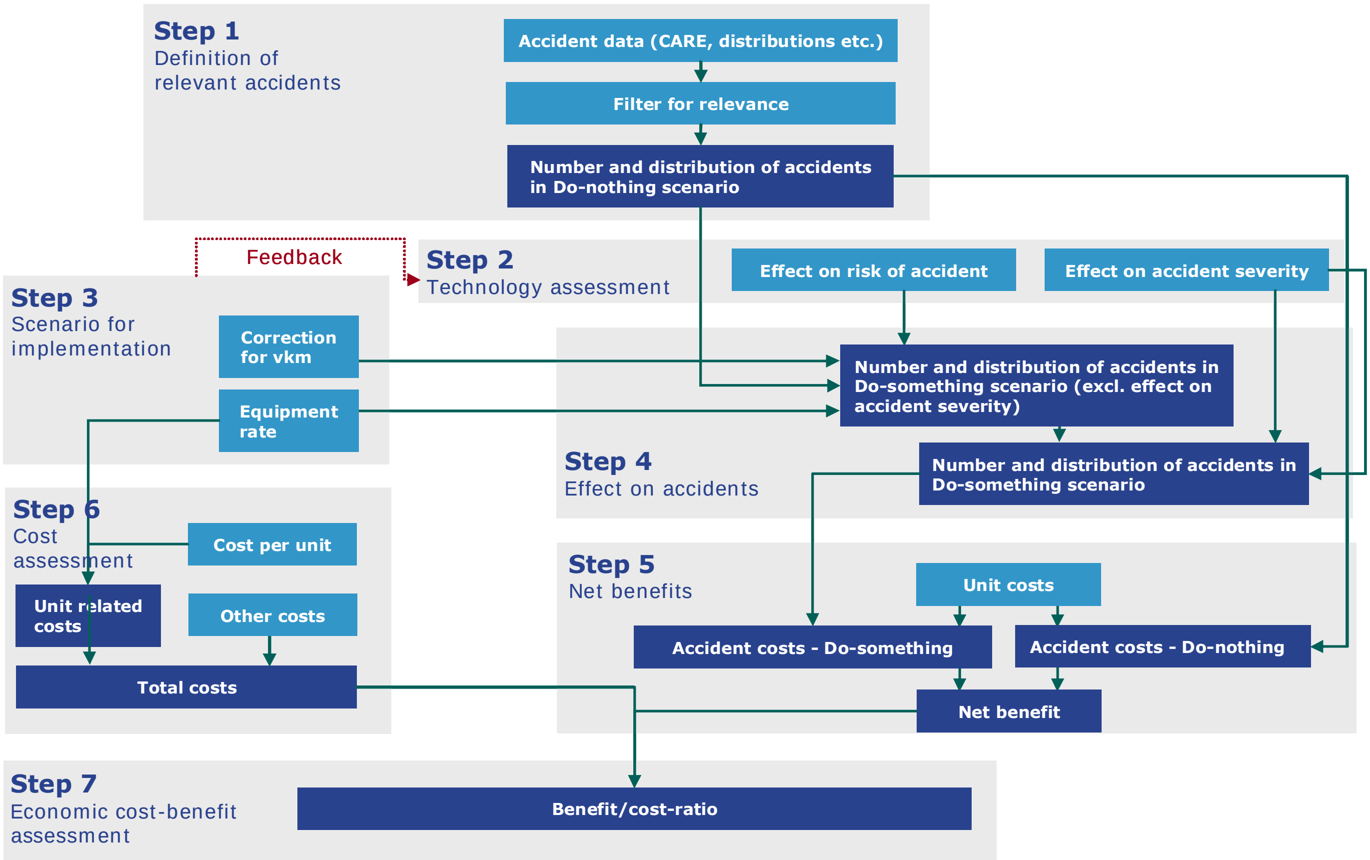
Table 2-2 List and short description of safety technologies

Type of device	Safety device		Short description
1. Avoiding collisions, mitigating their severity and their consequences	1.1	Electronic stability control (ESC)	Stability enhancing system which improves vehicles' lateral stability.
	1.2	Brake assist system (BAS)	System which helps to reduce the braking distance when an emergency brake is detected.
	1.3	Improved vehicle compatibility	Technology to reduce the severity of accidents involving vulnerable road users by improvements of the front design.
	1.4	Under-run protection	Under-run guard rails and side under-run protection
	1.5	eCall	Automatic call sent to emergency service in case of an accident.
	1.6	Soft nose on trucks	Absorption of energy in case of accidents with cars and trucks
	1.7	Collision warning and similar systems	The system informs the driver of dangerous situations in advance or activates a potential pre-crash /crash avoidance system.
	1.8	Adaptive cruise control (ACC)	A system which enables the vehicle to maintain a driver-defined distance from the preceding vehicle while driving within a maximum speed limit - set by the driver.
2. Linked to lack of perception	2.1	Daytime running lights	The use of daytime running lights improves vehicle visibility in all light conditions.
	2.2	Conspicuity marking	Contour-marking of HGV to increase visibility.
	2.3	Retro-fitting of blind spot mirrors	Installation in wide angle/close proximity mirrors on existing trucks to avoid blind spot accidents.
3. Linked to inappropriate speed	3.1	Intelligent speed adaptation (ISA)	Intelligent speed adaptation warns or prevents the driver from exceeding the local or preset speed limit.
4. Linked to lack of use and/or improper use of restraint systems	4.1	Seat belt reminders	Detectors in the seat inform the system if the seat is occupied and if the seat belt is not fastened.
	4.2	Improved seats and headrests	Improved design of seats and headrests to avoid whiplash injuries.
	4.3	Universal anchorage systems (ISOFIX)	Standard for installing child seats correctly into cars.
5. Linked to tyre problems	5.1	Tyre pressure monitoring systems	System which informs the driver of reduced pressure in one or more tires.
	5.2	Brake measurement devices	System which automatically tests the brakes.
6. Linked to driver distraction/impairment/behaviour	6.1	Alcohol ignition interlocks	The system checks the alcohol level of the driver (breath test).
	6.2	Fatigue detectors	The system monitors the condition of the driver, including tracking and warning of drowsiness, distraction and inattention.
	6.3	Event or accident data recorders	Accident data recorder is an on-board event recorder. In case of accidents (or events), data on the vehicle's speed, acceleration, brake use, etc. just prior to, during and after the accident is recorded.
	6.4	Lane departure warning	The system assists drivers in keeping their lanes by warning drivers when their car is in danger of leaving the lane unintentionally.

2.3 Approach

The assessment of each the 21 vehicle technologies is based on seven general steps, as illustrated in the figure below.

Figure 1 Assessment framework



The seven steps are briefly described below.

Step 1: Definition of relevant accidents
The first step is to identify the accidents which are relevant for the technology under consideration. For example, for the brake assistant system (BAS) only rear end and head on collisions, merging and intersection collisions, vehicle-pedestrian collisions, collisions with obstacles and left roadway accidents are relevant.

The identification of relevant accidents is based on compiled accident data (CARE[4] etc.) and existing literature.

The result is a scenario for the future development in the number of fatalities, severe injuries and slight injuries in a situation where the current development

[4] Community database on Accidents on the Roads in Europe

continues, as nothing extraordinary is done to promote the safety technology under consideration, i.e. the Do-nothing scenario.

Step 2: Technology assessment
The effectiveness of each of the technologies under consideration is assessed on the basis of a review of the relevant literature.

The benefits of implementing a certain safety technology can be in the form of reduced collision probability and/or severity of accidents in case an accident occurs.

Step 3: Scenario for implementation
The scenario for implementation refers to the diffusion of the safety technology within the vehicle fleet in the Do-something scenario, which is compared to the Do-nothing scenario, where nothing extraordinary is done to promote the use of the safety technology under consideration.

To ensure that the technologies are evaluated on equal premises the assessment compares costs and benefit of installing each technology in all (relevant) new vehicles from 2007 (except for *retro-fitting of blind spot mirrors)*.

It is taken into account that some of the technologies are already installed in some vehicles and that market penetration will possibly increase over the coming years even if nothing extraordinary is done to promote the use of the safety technology.

Step 4: Effect on accidents
The effect on the number of fatalities, severe injuries and slight injuries of making the installation of the technology in all new vehicles mandatory is assessed on the basis of the effectiveness of the technology (step 2) and the scenario for implementation (step 3).

Step 5: Net benefits
The economic net benefits are defined as a reduced number of fatalities/injuries. The net benefits are evaluated by assessing the accident costs in the Do-something scenario and the accidents costs in the Do-nothing scenario. The net benefits are estimated on the basis of the standard unit costs for accidents which were presented in Table 2-1.

The applied unit values have a large impact on the estimated benefit/cost-ratio. If higher values are used the benefit/cost-ratio will increase, and vice versa for lower unit values. The level of the applied unit values does not affect the relative ranking of the technologies.

Step 6: Cost assessment
The costs of installing the relevant technologies in all new vehicles are assessed in step 6.

Step 7: Economic cost-benefit assessment
The final step is to assess whether it is economically beneficial to implement the safety technology under consideration. The net benefits of the system (step 5) are compared to the net costs of installing the system in all new vehicles (step 6). If the net benefits outweigh the net costs, the introduction of the safety system will be beneficial to society. The robustness of the results to the values used for key parameters (e.g. unit cost per technology, effectiveness of system) is evaluated through a number of sensitivity analyses.

Finally, the technologies are ranked according to the estimated benefit/cost-ratio.

2.4 Key input figures

The economic cost-benefit assessment is, as mentioned, based on the assessment of a number of parameters for each technology.

The most important parameters for each of the technologies are summarised in the table below. Please note that the information on the effectiveness of the technologies presented in the table only reflects the effectiveness in terms of avoiding fatal accidents or reducing the severity of the previously fatal accidents to severe or slight injury. A similar assessment is made for severe and slight injuries.

The table shows, for example, that the brake assistant system (BAS) will result in a 8% reduction in the risk of collision for rear end and head on collisions, merging and intersection collisions, vehicle-pedestrian collisions, collisions with obstacles and left roadway accidents, which account for approximately 50% of all fatal accidents. Likewise, it is estimated that the risk of the accident being fatal is reduced by 8% (reduced to severe injury) for the above mentioned type of accidents. Furthermore, it can be seen that it is estimated that 5% of the current fleet of vehicles have the brake assistant system installed. This figure is estimated to increase to 20% in 2025 even if nothing extraordinary is done to promote the system. Finally, the table shows that it has not been possible to obtain any solid cost estimates on the brake assistant system.

The data on the share of vehicles with the technology installed in 2006 and 2025 and the evaluation of the effectiveness of the technology are used to estimate the number of saved fatalities/injuries.

Table 2-3 Overview - key input data for each technology

Technology	Do-nothing scenario		Effectiveness of technology (fatalities)			Unit costs
	Share of vehicles 2006	Share of vehicles 2025	Reduction, risk of collision	Reduction, severity	Accident group	
1.1 Electronic stability control (ESC)	9%	50%	18%	0%[5]	All	€250
1.2 Brake assist system (BAS)	5%	20%	8%	8%	Rear end and head on/merging and intersection/vehicle-pedestrian collisions, collisions with obstacles and left roadway accidents (50% of all)	N/A
1.3 Improved vehicle compatibility	0-1%	50%	0%	28%	Vulnerable road users hit by front of car (14% of all)	N/A
1.4 Under-run protection	0-1%	10%	0%	39%	Vulnerable road users hit by a HGV turning right and cars hitting trucks in the side (2.5% of all)	€1250
1.5 eCall	0-1%	0-1%	0%	4%	All	€90-€500
1.6 Soft nose on trucks	Virtually no cost-benefit data					
1.7 Collision warning and similar systems	0-1%	20%	12%	8%	Rear and head/side/merging and intersection/vehicle-pedestrian collisions, collisions with obstacles and left roadway accidents (60% of all)	N/A
1.8 Adaptive cruise control (ACC)	1%	10%	25%	20%	Rear end collisions (4-6% of all)	€750
2.1 Daytime running lights	10%[1]	10%[1]	15%	0%[5]	Multi-party daytime accidents (40% of all, ex. countries where DRL is compulsory)	€25
2.2 Conspicuity marking	5%	5%	86%	0%[5]	Accident during night-time or dusk/dawn on street without lighting involving a car hitting a HGV at the rear or at the side (0.45% of all)	€204
2.3 Retro-fitting of blind spot mirrors	14%	100%[2]	40%	0%[5]	Vulnerable road users hit by a HGV turning right (1.25% of all)	€210
3.1 Intelligent speed adaptation (ISA)	0-1%	20%	50%	0%[5]	Rear end and head on collisions, merging and intersection collisions, vehicle-pedestrian collisions, collisions with obstacles and left roadway acc. (50% of all)	€500
4.1 Seat belt reminders	0%[3]/ 10%[4]	0%[3]/ 90%[4]	0%[3]/ 0%[4]	46%[3]/ 43%[4]	Accidents with drivers not wearing seat belts (33% of all in EU-15 and 50% of all in NMS)	€60[3]/ €50[4]
4.2 Improved seats and headrests	Virtually no cost-benefit data					
4.3 Universal anchorage systems (ISOFIX)	Virtually no cost-benefit data					
5.1 Tyre pressure monitoring systems	0-1%	0-1%	100%	0%	Accidents caused by tyre pressure problems (0.08% of all)	€125
5.2 Brake measurement devices	Virtually no cost-benefit data					
6.1 Alcohol ignition interlocks	0-1%	10%	75%	0%[5]	Accidents with at least one drunk driver involved (30% of all in EU-15 and 40% of all in NMS)	€500
6.2 Fatigue detectors	0-1%	10%	10%	0%[5]	(95% of all)	N/A
6.3 Event or accident data recorders	0-1%	10%	15%	0%	All accidents with cars, trucks and buses (95% of total)	€100
6.4 Lane departure warning	0-1%	10%	25%	15%	Head on accidents, single accidents and side collisions (50% of total)	€400

[1] In countries where DRL is not compulsory, [2] As mandatory in all new trucks, [3] Version which blocks the vehicles, [4] Version which gives a discreet visual and/or audio signal, [5] For some of these technologies it could be argued that there is an effect on the severity in case an accident occurs. However, this effect is not explicitly taken into account here due to a lack of data. For some technologies the effect is 'included' in the estimate on the reduction in the risk of accidents.

2.5 Effect on the number of fatalities/injuries

The estimated effects on the total number of fatalities, severe injuries and slight injuries are presented in Figure 2 - Figure 4 below for selected years. The estimated effects depend on:

- The definition of 'relevant accidents'
- The Do-nothing scenario
- The estimated effectiveness in terms of reducing the risk of collision and/or severity of injuries in case an accident occurs.

Figure 2 Reduction in the number of fatalities in EU-25 in 2010 and 2020

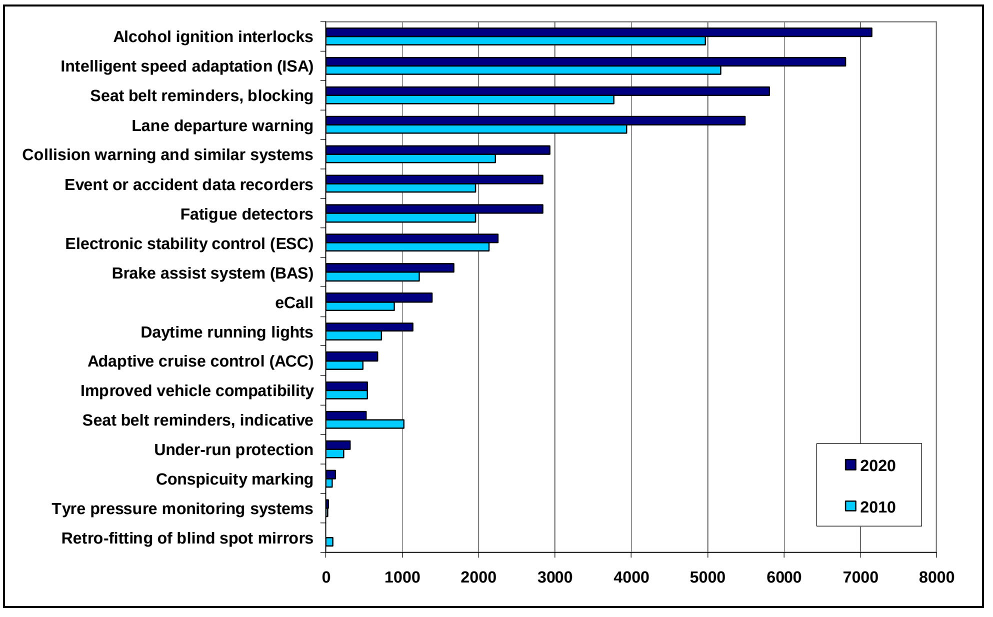


Figure 3 Reduction in the number of severe injuries in EU-25 in 2010 and 2020

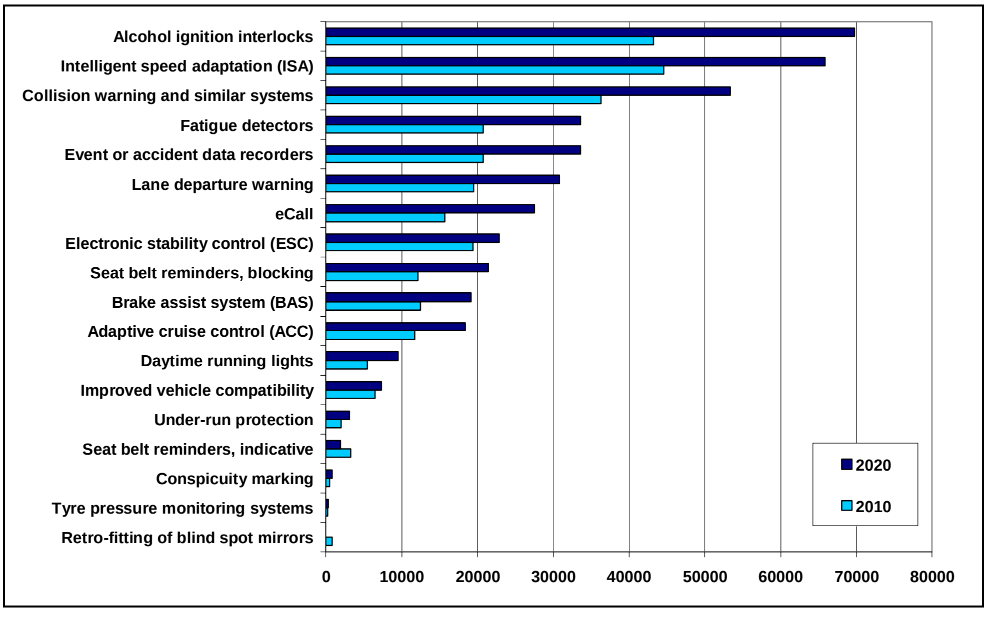
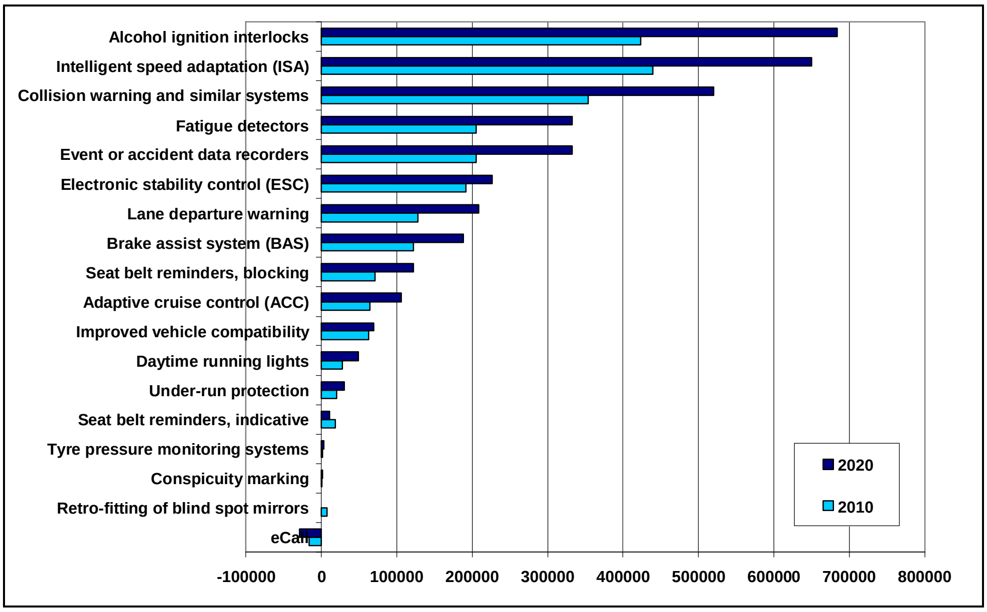


Figure 4 Reduction in the number of slight injuries in EU-25 in 2010 and 2020



It can be seen that:

– Some of the technologies will have a very large impact on the number of fatalities/injuries in EU-25

– The technologies with the largest impact are:
  - Alcohol ignition interlocks
  - Intelligent speed adaptation (ISA)
  - Seat belt reminders (depending on system)
  - Lane departure warning system
  - Collision warning and similar systems
  - Event or accident data recorders
  - Fatigue detectors

– The technologies with the lowest impact in total are:
  - Tyre pressure monitoring systems
  - Retro-fitting of blind spot mirrors
  - Conspicuity marking
  - Under-run protection.

It is worth noting that some of the technologies with the lowest total impact are efficient in terms of reducing specific type of accidents.

The benefits of a reduced number of fatalities/injuries are compared to the cost of installing the technology in all new cars in the next section.

2.6 Results and conclusions

The results of the economic cost-benefit analysis are summarised in the table below.

The benefit/cost-ratio is estimated for 13 of the 21 technologies. For 4 additional technologies the break-even unit costs have been estimated, as no solid cost estimates are available in the existing literature. If the actual unit costs are lower than the estimated break-even unit costs, the technology can be considered as being cost-effective. For 4 of the technologies virtually no cost-benefit data is available.

Table 2-4 Summary - main results of economic cost-benefit assessment (Benefit/cost-ratio, BCR)

Category - according to economic cost-effectiveness	Technology	Benefit/cost-ratio (BCR) Central estimate	Comment
1. Cost-effective (BCR>3)	▪ Seat belt reminders	7.6-8.2	Depending on system
	▪ Event or accident data recorders	7.1	
	▪ Electronic stability control (ESC)	3.8	
	▪ Retro-fitting of blind spot mirrors	3.8	
	▪ Intelligent speed adaptation (ISA)	3.3	
	▪ Alcohol ignition interlocks	3.1	
2. Most likely cost-effective (1<BCR<3)	▪ Conspicuity marking	2.5	
	▪ Under-run protection	2.4	
	▪ Daytime running lights	1.8	
	▪ Lane departure warning	1.7	
3. Most likely not cost-effective (0.25<BCR<1)	▪ Adaptive cruise control (ACC)	0.4	
4. Not cost-effective (BCR<0.25)	▪ Tyre pressure monitoring systems	0.04	
Difficult to categorise	▪ eCall	0.4-2.0	Depending on cost estimate
Break-even cost calculated	▪ Collision warning system	Break-even costs = €1,200/vehicle	
	▪ Fatigue detectors	Break-even costs = €710/vehicle	
	▪ Improved vehicle compatibility	Break-even costs = €285/vehicle	
	▪ Brake assistant systems	Break-even costs = €460/vehicle	
Virtually no cost-benefit data	▪ Soft nose on trucks		
	▪ Improved seats and headrests		
	▪ Brake measurement devices		
	▪ Universal anchorage systems (ISOFIX)		

It can be concluded that:

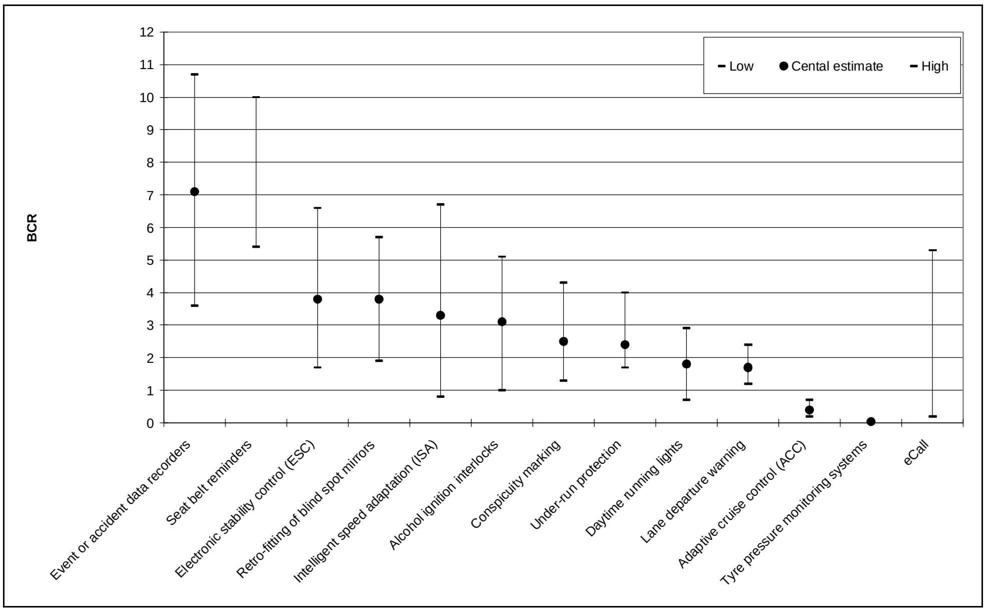
- A large number of the technologies under consideration appear to be either *cost-effective* (benefit/cost-ratio>3) or *most likely cost-effective* (benefit/cost-ratio between 1 and 3)
- *Seat belt reminders* and *event or accident data recorders* appear to be the most cost-effective vehicle technologies, but it also appears that *electronic stability control (ESC), retro-fitting of blind spot mirrors, intelligent speed adaptation (ISA)* and *alcohol ignition interlocks* are very promising.
- The 3 vehicle technologies which directly address accidents involving HGV; *retro-fitting of blind spot mirrors, conspicuity marking* and *underrun protection* are considered to be *cost-effective* or *most likely cost-effective*. The cost-effectiveness of retro-fitting of blind spot mirrors depends crucially on the year of implementation. The sooner the initiative is implemented the more cost-effective.
- It has proven difficult to provide solid evidence on the cost-effectiveness of the in-vehicle emergency system *eCall* to due a lack of solid estimates of the total cost of the system.
- *Adaptive cruise control (ACC)* and *tyre pressure monitoring systems* appear to be less cost-effective measures to improve road safety.
- For 4 technologies, no benefit/cost-ratio has been estimated due to a lack of solid cost estimates. Some of these systems seem to be effective, but further research is needed to determine their cost-effectiveness.
- For the final 4 vehicle technologies, virtually no cost-benefit data is available. Due to the nature of the technologies, it could prove difficult to assess the cost-effectiveness of the systems, even if further research is conducted. This does however not necessarily mean that the technologies are not cost-effective measures for improving the safety on the European roads.

The robustness of the results has been analysed through a number of sensitivity analyses for each of the technologies. The results of the sensitivity analyses are summarised in Figure 5 for the technologies for which a benefit/cost-ratio is estimated and in Figure 6 for the technologies for which a break-even unit cost is estimated.

The fact that a large number of the technologies under consideration appear to be either *cost-effective* or *most likely cost-effective* is robust to the assumptions made.

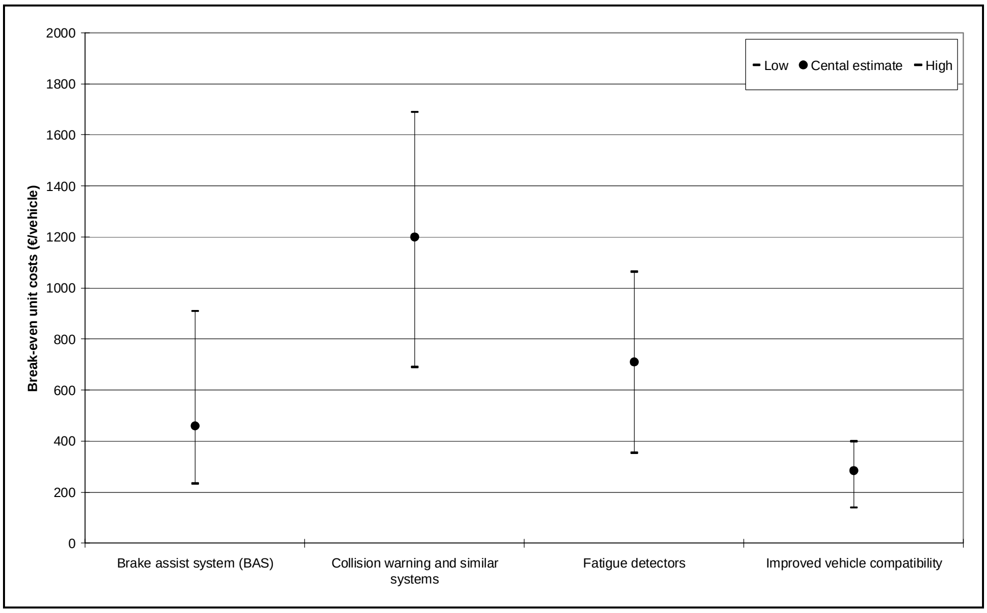
The sensitivity analyses show that the results are highly dependent on the unit cost estimate and the assessed effectiveness of the technology. The results are insensitive to the assumed market penetration rates for the Do-nothing scenario and the assumed lifetime of the vehicle.

Figure 5 Range of BCR for each technology based on sensitivity analyses



Note: No central estimate is given for seat belt reminders and eCall, as more than one scenario is assessed (ref. Table 2-4)

Figure 6 Range of break-even unit costs for each technology based on sensitivity analyses



Finally, it should be noted that the costs of the technologies tend to decrease over time, which could make some of the currently least cost-effective measures cost-effective in the future.

3 Framework

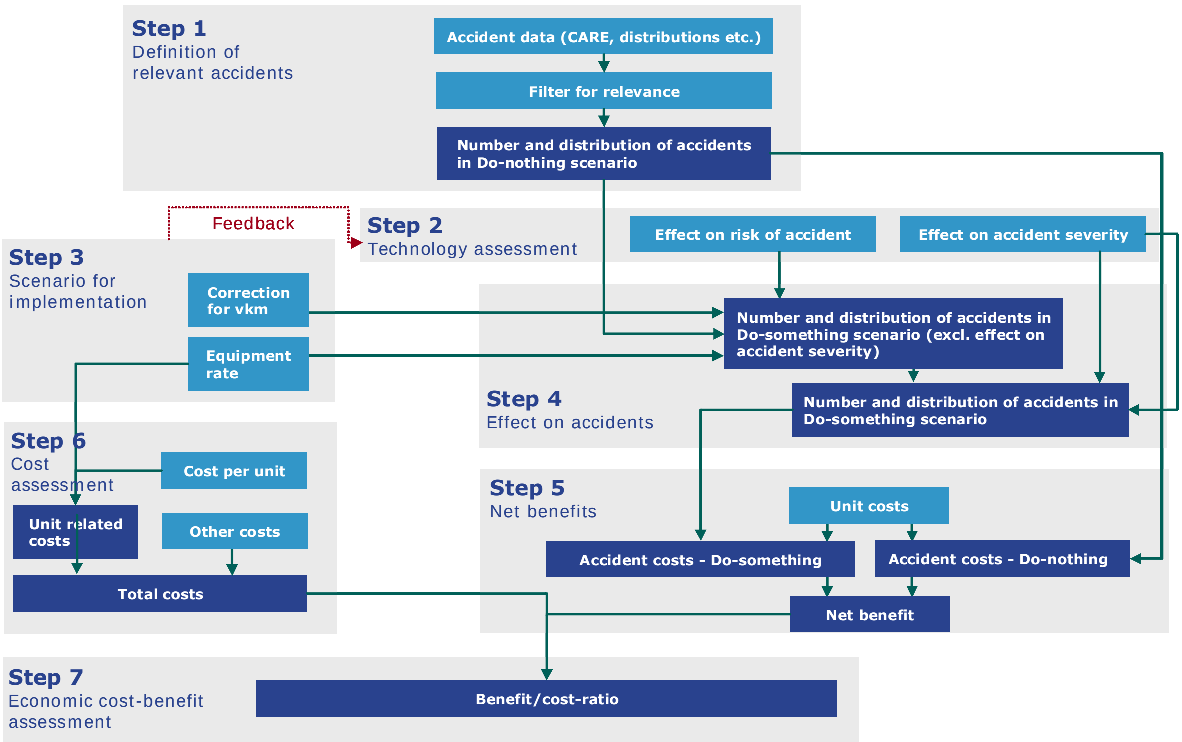
The general framework for the assessment of the vehicle safety technologies is set out in this section.

3.1 Assessment methodology

The assessment methodology applied here is closely related to the approach taken in the SEiSS study (VDI/VDE/IT, IFV Köln (2005)), though a number of minor changes have been made to accommodate the requirements of this study.

The assessment methodology applied here is outlined in the figure below. The approach builds on seven general steps, which are briefly described in this section. The approach to assessing safety impacts (steps 1-4) is described in detail in chapter 3, while the approach to economic cost-benefit analysis is described in detail in chapter 4.

Figure 7 Assessment framework



Step 1: Definition of relevant accidents
The first step is to identify the accidents which are relevant for the technology under consideration. For example, for the brake assistant system (BAS) only rear end and head on collisions, merging and intersection collisions, vehicle-pedestrian collisions, collisions with obstacles and left roadway accidents are relevant.

The identification of relevant accidents is based on compiled accident data (CARE[5] etc.) and existing literature.

The result is a scenario for the future development in the number of fatalities, severe injuries and slight injuries in a situation where the current development continues, as nothing extraordinary is done to promote the safety technology under consideration, i.e. the Do-nothing scenario.

Step 2: Technology assessment
The effectiveness of each of the technologies under consideration is assessed on the basis of a review of the relevant literature.

The benefits of implementing a certain safety technology can be in the form of reduced collision probability and/or severity of accidents in case an accident occurs.

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[5] Community database on Accidents on the Roads in Europe

Step 3: Scenario for implementation
The scenario for implementation refers to the diffusion of the safety technology within the vehicle fleet in the Do-something scenario, which is compared to the Do-nothing scenario, where nothing extraordinary is done to promote the use of the safety technology under consideration.

To ensure that the technologies are evaluated on equal premises, the assessment compares costs and benefit of installing each technology in all (relevant) new vehicles from 2007 (except for *retro-fitting of blind spot mirrors)*.

It has been taken into account that some of the technologies are already installed in some vehicles and that market penetration will possibly increase over the coming years even if nothing extraordinary is done to promote the use of the safety technology.

Step 4: Effect on accidents
The effect on the number of fatalities, severe injuries and slight injuries of making the installation of the technology mandatory in all new vehicles is assessed on the basis of the effectiveness of the technology (step 2) and the scenario for implementation (step 3).

Step 5: Net benefits
The economic net benefits are defined as a reduced number of fatalities/injuries. The net benefits are evaluated by assessing the accident costs in the Do-something scenario and the accidents costs in the Do-nothing scenario. The net benefits are estimated on the basis of the standard unit costs for accidents which were presented in Table 2-1.

The applied unit values have a large impact on the estimated benefit/cost-ratio. If higher values are used the benefit/cost-ratio will increase, and vice versa for lower unit values. The level of the applied unit values does not affect the relative ranking of the technologies.

Step 6: Cost assessment
The costs of installing the relevant technologies in all new vehicles are assessed in step 6.

Step 7: Economic cost-benefit assessment
The final step is to assess whether it is economically beneficial to implement the safety technology under consideration. The net benefits of the system (step 5) are compared to the net costs of installing the system in all new vehicles (step 6). If the net benefits outweigh the net costs, the introduction of the safety system will be beneficial to society. The robustness of the results to the values used for key parameters (e.g. unit cost per technology, effectiveness of system) is evaluated through a number of sensitivity analyses.

Finally, the technologies are ranked according to the estimated benefit/cost-ratio.

3.2 Traffic safety devices under consideration

The table below shows the list of considered technologies together with a short description of the technologies.

Table 3-1 List and short description of safety technologies (continued on next page)

Type of device - Reduce casualties/injuries by…	Safety device		Short description
1. Avoiding collisions, mitigating their severity and their consequences	1.1	Electronic stability control (ESC)	A stability enhancing system which improves vehicles' lateral stability by electronically detecting and automatically assisting drivers in dangerous situations (e.g. over - and under-steer) and under unfavourable conditions (e.g. snow).
	1.2	Brake assist system (BAS)	A system which helps reduce the braking distance when an emergency brake is detected.
	1.3	Improved vehicle compatibility	Improved vehicle compatibility improves conditions for vulnerable road users by making improvements to the cars so that the consequences of hitting a pedestrian or a cyclist with the car are less severe.
	1.4	Under-run protection	Under-run guardrails on the back of lorries and large trailers are designed to prevent cars and other vehicles from driving under the overhang of large vehicles. The objective of side under-run protection is, first and foremost, to prevent pedestrians and road users riding two-wheeled vehicles from being run over, by getting caught in the open space between the wheel axles on large vehicles.
	1.5	eCall	Emergency call automatically sent to the emergency services in case of accident.
	1.6	Soft nose on trucks	Absorption of energy in case of accidents with cars and trucks.
	1.7	Collision warning and similar systems	In a collision or obstacle warning system predictive sensors calculate the likelihood of a crash. An appropriate warning system can inform the driver of dangerous situations in advance or activate a potential pre-crash /crash avoidance system.
	1.8	Adaptive cruise control (ACC)	A system which enables the vehicle to maintain a driver-defined distance from the preceding vehicle while driving within a maximum speed limit - set by the driver. If there is a rapid reduction in the vehicle's speed, the system will warn the driver and switch off for driver control.
2. Preventing accidents linked to lack of perception	2.1	Daytime running lights	The use of daytime running lights improves vehicle visibility in all light conditions.
	2.2	Conspicuity marking	Contour-marking of HGV provides a high degree of conspicuity and reduces the reaction time of car drivers.

	2.3	Retro-fitting of blind spot mirrors	Installation in wide angle/close proximity mirrors on existing trucks to avoid blind spot accidents.
3. Preventing accidents linked to inappropriate speed	3.1	Intelligent speed adaptation (ISA)	Vehicles equipped for intelligent speed adaptation warn or prevent the driver from exceeding the local speed limit. Speed limits are obtained either by comparing vehicle location by means of GPS to an in-vehicle speed limit database or by transmission of speed limits to the vehicle by roadside beacons
4. Linked to lack of use and/or improper use of restraint systems	4.1	Seat belt reminders	Small detectors in the seat inform the system if the seat is occupied and if the seat belt is fastened. The seat belt reminder system can be installed in both the front seats and the rear seats and can be either indicative or blocking.
	4.2	Improved seats and head-rests	Improved design of seats and headrests to avoid whiplash injuries
	4.3	Universal anchorage systems (ISOFIX)	A standard for installing child seats into cars.
5. Preventing casualties linked to tyre problems	5.1	Tyre pressure monitoring systems	Information to driver of reduced pressure in one or more tires.
	5.2	Brake measurement devices	An on-board electronic system which automatically tests the brakes.
6. Preventing accidents linked to driver distraction/impairment/behaviour	6.1	Alcohol ignition interlocks	The system checks the alcohol level of the driver (breath test) when starting the vehicle and prevents the start of the vehicle if the driver is intoxicated. During driving the system also checks intoxication at specific intervals and takes preventive actions with pre-warning.
	6.2	Fatigue detectors	The system monitors the condition of the driver. Presently discussed parameters are tracking and warning of drowsiness, distraction and inattention.
	6.3	Event or accident data recorders	The accident data recorder is an on-board event recorder. In case of accidents (or events), data on the vehicle's speed, acceleration, brake use, etc. just prior to, during and after the accident is recorded. This data can subsequently be downloaded from the accident data recorder and used to analyse how the vehicle was driven at the time of the accident. This knowledge can serve scientific, technical and legal purposes.
	6.4	Lane departure warning	Lane departure warning systems assist drivers in keeping their lanes by warning drivers when their car is in danger of leaving the lane unintentionally.

4 Approach for safety assessment (steps 1-4)

The general approach to assessing safety impacts is described in detail in this section.

4.1 Definition of relevant accidents (step 1)

The accident data used is described below.

4.1.1 Accident statistics

The assessment of the number and distribution of accidents relevant for each of the different vehicle safety devices is based on the CARE database. CARE is a community database on reported road accidents resulting in death or injury. There are no statistics on material damage accidents.

National data sets for individual accidents are integrated into the CARE database in their original national structure and definitions. Transformation rules are implemented to increase data compatibility and enhance the functionality of the system. While the homogenisation process is still underway, the inherent incompatibility of national accident data remains a source of possible misinterpretation when performing comparative analyses at international level. On-line access to the CARE database is currently restricted to expert users[6].

This study therefore uses data processed and forwarded by the Commission as well as other accessible reporting on European accident statistics.

Identification of relevant accidents
The available data covers general information on the annual number of accidents, injuries and fatalities for the 25 individual member states in the period 1991-2002. Preliminary statistics indicate that the number of injury accidents and casualties in 2003-2004 is lower than in 2002.

For EU-15[7] there are national details for fatalities distributed on:

[6] SAFETYNET (2005)
[7] Excluding Germany in 1993-2002, Italy in 1999-2002 and Belgium and Greece in 2002

- Vehicle type in 1993-2002
- Age and gender in 1993-2002
- Vehicle types and age in 2002
- Vehicle types and type of collision in 2002
- Type of collision in 2002
- Vehicle types and urban/rural area in 2002
- Type of area in 2002
- Type of junction in 2002
- Weather conditions in 2002
- Months in 2002
- Day of week in 2002
- Time of day in 2002[8]

Furthermore, fatalities distributed on drivers, passengers and pedestrians and on vehicle types are available for EU-15 for 2002.

The statistics are not always complete, detailed data is not available for all countries, nor do sums always add up to the stated totals. However, the database is considered to be a sound basis for this work.

Identification of the total potential for road safety improvement for each of the examined vehicle safety devices is a two-step process. First the target group of accidents relevant for each of the examined vehicle safety devices is identified. Secondly accident data from the CARE database and possibly supplementary information are used to make an estimate of the number of impressionable injury accidents and casualties at EU level.

Where relevant details on specific accident types are not directly available the estimate is based on the best possible qualitative assessment.

4.1.2 Non-reported accidents

Whether a road accident is reported and registered in the official national accident databases mainly depends on whether motor vehicles are involved in the accident, and on the severity of the accident. While fatal accidents are nearly always reported, there is a substantial underreporting of other injury and material accidents in most countries. Reporting is usually especially low for pedestrian and cyclist accidents. Reporting also differs dependent on age groups, type of accidents and roads, time of day, season, etc. Furthermore studies show that the quality and coverage of accident statistics vary from country to country, primarily due to different reporting practices in the member states.

[8] SAFETYNET (2005)

In HEATCO (2005b)[9] it is thus stated that:

"Correction factors for road transport are likely to be different in different countries. Whenever national estimates for correction factors are available, we should therefore use these national factors. However, such factors are only available for 6 countries (Sweden, Denmark, Norway, Switzerland, Germany and UK). For all other countries we have to transfer values – e.g. the average value derived from the results from these 6 countries. Cautious estimates of the average correction factors for unreported accidents are given in the table below. The correction factor given for fatalities of 1.02 should be applied in all countries alike, since here the problem is not underreporting, but that some accidents victims die only after the first 30 days after the accident".

Table 4-1: Recommendation for European average correction factors for unreported road accidents

	Fatality	Serious injury	Slight injury	Average injury	Damage only
Average	1.02	1.50	3.00	2.25	6.00
Car	1.02	1.25	2.00	1.63	3.50
Motor-bike/moped	1.02	1.55	3.20	2.38	6.50
Bicycle	1.02	2.75	8.00	5.38	18.50
Pedestrian	1.02	1.35	2.40	1.88	4.50

Source: HEATCO (2005b)

Other sources confirm that underreporting of road accidents is a serious concern, for example in connection with analysing and prioritising accident problems, in estimations of economic benefits of reducing accidents, etc. In ICF (2003) undercounting of serious and slight injuries is given at approx. 33% and 58% on average for the Netherlands, Sweden and the UK. These values vary considerably from country to country though, as also stated in Transportøkonomisk Institutt (1997) (i.e. the Norwegian *Trafikksikkerhetshåndbok*/Road Safety Handbook). The best estimate given here is coverage of 100% for fatal accidents, 50% for accidents with serious injuries and 30% for accidents with slight injuries. Coverage for accidents with only material damage is very low.[10]

Based on these different recommendations for counteracting the underreporting of road accidents, this study writes up the registered accidents in the CARE database with corrections factors as shown in Table 4-2.

[9] HEATCO is an EU 6th framework research project, which aims at developing harmonised guidelines for transport costing and project appraisal.

[10] Transportøkonomisk Institutt (1997)

Table 4-2 Correction factors for underreporting of accidents

	Fatalities	Serious injuries	Slight injuries
EU-15	1.0	1.5	3.0
NMS	1.0	2.5	4.0

Due to the lack of adequate references, different correction factors have not been applied to individual countries. The only distinction made is between EU-15 and the new member states. It has been assumed that underreporting in general is more widespread in the NMS, although e.g. the varying distribution of fatalities and injuries in the different countries indicates that underreporting is likely to vary considerably more between the individual member states. Also the definition of the severity of a traffic casualty differs among countries, cf. definitions given in the CARE PLUS glossary for the variables included in the database.

On the basis of the correction factors for non-reported accidents, a database on fatalities, severe injuries and slight injuries has been established, covering all countries in EU-25.

4.2 Technology assessment (step 2)

The effectiveness of each of the technologies under consideration is assessed on the basis of a review of the relevant literature.

The benefits of implementing a certain safety technology can be in the form of reduced collision probability and/or severity of accidents in case an accident occurs. In practice the data outlined in the two tables below was collected for each of the technologies under consideration. This is assessed for all the technologies under consideration, taking into account the scenario for implementation.

Please note that x, y and z are numbers from 0-100 and differ for each technology. The same goes for each of the numbers in the cells of Table 4-4.

Table 4-3 Reduction in collision probability

Fatalities	x%
Severe injuries	y%
Slight injuries	z%

Table 4-4 Accident severity matrix

Before	After			
	Fatalities	Severe injuries	Slight injuries	Avoided
Fatalities changing to…		%	%	%
Severe injuries changing to…	%		%	%
Slight injuries changing to…	%	%		%

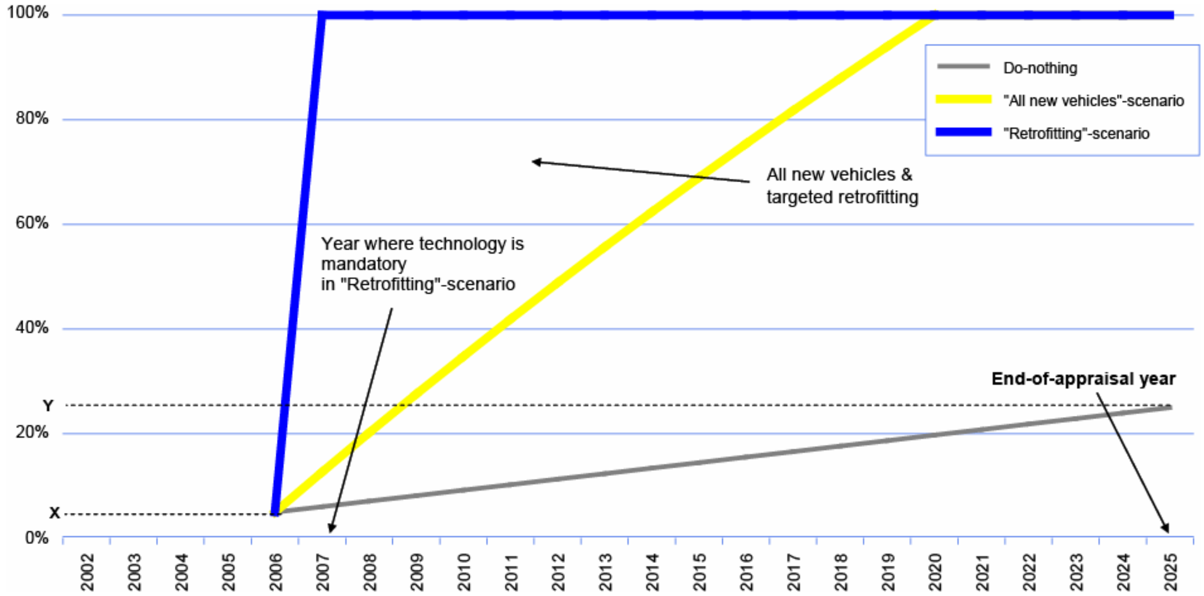
4.3 Scenario for implementation (step 3)

A key issue when assessing and comparing a large number of technologies is to ensure that they are compared on equal premises. This implies that the Do-something scenario(s) which are compared to the Do-nothing scenario must be comparable across technologies. Again this means that the scenarios which are analysed are stylised presentations of possible future developments.

4.3.1 General approach

The general approach to the scenario definition used here is outlined in the figure below.

Figure 8 Approach to the definition of scenarios (share of vehicles with technology)



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There are 3 stylised scenarios which are relevant here:

1. **Do-nothing scenario**, which entails that the current development continues as nothing extraordinary is done to promote the safety technology under consideration, i.e. this scenario is based on business-as-usual conditions. This is illustrated by the grey line in the figure above, where "X" reflects market penetration or deployment of the technology under consideration in 2006, and "Y" the market penetration or deployment in the end-of-appraisal year with no extra measures to accelerate the roll-out of the technology . Both X and Y can be 0% and differ for each of the technologies.

2. **"All new vehicles" scenario**, which entails that the technology is installed in all new vehicles. This is illustrated by the yellow line. This entails - in this stylised example - that from 2007, all new cars will have the relevant technology installed. Given an assumed lifetime of vehicles of 14 years, all vehicles without the technology will then be phased out in 2020.

3. **"Retro-fitting" scenario**, which entails that the technology is retro-fitted in all relevant vehicles built before 2007 and which at that time do not have the technology installed. This scenario is illustrated by the blue line.

The "retro-fitting" scenario of course represents a more ambitious scenario, but still the "all new vehicles" scenario is rather ambitious compared to many of the scenarios analysed in other studies of vehicle safety technologies.

In eSafety Forum Working Group (2005) it is, for example, estimated that only ESC could be deployed in a "very high percentage (80-100%)" of the vehicles in 2020. However, to ensure that all technologies are evaluated on equal premises it has been decided here to make the prioritisation on the basis of the "stylised scenario". Hence, the results are not influenced by choices of implementation scenarios.

For most technologies, the economic cost-benefit assessment is based on a comparison of costs and benefits under the "all new vehicles" scenario compared to costs and benefits in the Do-nothing scenario. In fact, the "retro-fitting" scenario is only relevant for a specific case, which evaluates the costs and benefits of retro-fitting blind spot mirrors to HGV.

In the remainder of the report, the "all new vehicles" scenario is referred to as the Do-something scenario unless otherwise stated.

4.3.2 Forecasting of vehicle stock

The scenarios defined above referred to the share of the vehicle fleet. To transform these figures to the *number of vehicles,* a forecast for the future development in the vehicle fleet is needed.

Passenger cars

The future number of vehicles in EU-25 is estimated on the basis of data from ANFAC. The data is shown in the table below. For 2005-2025 the estimates are based on the assumption that the vehicle fleet grows by 1% p.a.

Table 4-5 Vehicle stock - passenger cars, EU-25 (million vehicles)

	2003
Vehicle stock	213.1

Source: ANFAC

The Do-nothing scenario is, as mentioned above, based on estimates of market penetration in 2006 ("X") and the market penetration in the end-of-appraisal year ("Y").

It is assumed that the market penetration rate shows a linear growth over the appraisal period. Hence the number of vehicles with the technology implemented can, for any given year, be estimated by multiplying the number of vehicles with the relevant market penetration rate.

To analyse the importance of the assumed market penetration rates, several sensitivity analyses have been conducted. The results of these sensitivity analyses are presented at the end of chapters 6-22. The analyses show that the assumed market penetration rate for the Do-nothing scenario is of minor importance to the results.

The estimate of the phase-out of vehicles is based on an assumed average lifetime of a vehicle. In EU-15 the average economic lifetime of a car amounts to 11.4 years, whereas the average lifetime of a car in the new member states is 50% higher[11]. Hence it is assumed that vehicles are phased out at the age of 14, which is in line with most other studies which refer to a lifetime in the range of 12-16 years[12].

To analyse the importance of this assumption several sensitivity analyses have been conducted. The results of these sensitivity analyses are presented at the end of chapters 6-22. The analyses show that the assumed average lifetime of the vehicle is of minor importance to the results.

Given this information, the fleet development can be forecast for the Do-nothing scenario.

Similarly the future composition of the fleet for the Do-something scenario ("all new vehicles") can be estimated, based on the assumption that the relevant technology is installed in all new vehicles as from 2007 and onwards.

[11] VDI/VDE/IT, IFV Köln (2005)

[12] For example: ICF (2003), TNO (unknown) and VDI/VDE/IT, IFV Köln (2005)

The development in the vehicle fleet for the Do-nothing and the Do-something scenario can be used directly to estimate the difference in total unit related costs of implementing the safety devices when the unit costs (i.e. costs per device) are known.

Heavy goods vehicles
Data on the size of the fleet of HGV >3.5 tons are available for EU-15 for year 2002 (see Table 4-6). Data is however not readily available for the new member states. The size of the fleet in the new member states is estimated on the basis the fleet data for EU-15 and data on the number of newly registered HGV >3.5 tons, which is available for EU-23 (see Table 4-6).

Table 4-6 Number of HGV > 3.5 tons in EU-15

Country	2002
Austria	339,000
Belgium	154,000
Denmark	49,000
Finland	72,000
France	560,000
Germany	1,158,000
Greece	255,000
Ireland	52,000
Italy	868,000
Luxembourg	20,000
Netherlands	192,000
Portugal	143,000
Spain	408,000
Sweden	76,000
United Kingdom	548,000
EU (15)	4,899,000

Source: TÜV (2003, page 53)

Table 4-7 New registration of commercial vehicles >3.5 tons in EU-23

Country	2004	2005 (Jan-Jun)	2005 (Full year)
Austria	9,690	4,536	9,072
Belgium	10,378	6,891	13,782
Denmark	4,664	2,828	5,656
Finland	4,519	2,250	4,500
France	47,477	28,884	57,768
Germany	92,463	50,047	100,094
Greece	2,232	1,049	2,098
Ireland	4,274	3,527	7,054
Italy	36,193	18,064	36,128
Luxembourg	1,038	634	1,268
Netherlands	14,387	8,410	16,820
Portugal	4,687	2,261	4,522
Spain	37,283	20,227	40,454
Sweden	5,236	2,925	5,850
United Kingdom	54,553	27,582	55,164
EU-15	329,074	180,115	360,230
Czech Republic	6,502	3,745	7,490
Estonia	638	393	786
Hungary	0	0	0
Latvia	886	487	974
Lithuania	1,658	905	1,810
Poland	12,541	5,509	11,018
Slovakia	2,849	1,463	2,926
Slovenia	1,474	744	1,488
New EU Members	26,548	13,246	26,492
Total EU-23	355,622	193,361	386,722

Note: 2005 (full year) estimated by assuming the same no. of registrations in second half 2005 as first half 2005. No data for Cyprus and Malta.

Source: ACEA website

The figures indicate that for EU-15 the annual number of new registrations is 5-10% of the fleet. The analysis presented here is based on the assumption that the average share is 8%. This figure is used to produce a rough estimate on the fleet of HGV > 3.5 tons in the new member states. For other years the estimates are based on the assumption that the vehicle fleet grows by 1% p.a.

4.3.3 Forecasting the safety situation

The development in the size and composition of the vehicle fleet can not necessarily be used directly to estimate the development in the future number of accidents, even if the effectiveness of the technology in relation to reducing the risk of collision and the severity of accidents is known. It has to be considered whether it is fair to assume that exposure in traffic in the form of vehicle-km increases with the growth rate in the vehicle fleet and what it is fair to assume on how crash and casualty rates will change due to improved vehicles and roads, even if nothing extraordinary is done to promote the technology under consideration.

It is therefore a challenge to forecast the future safety level on the roads. However, historical developments as well as research may give some hints on what is reasonable to assume about the above mentioned factors, keeping in mind that it is a goal in itself to ensure that the results of the analysis are as transparent and comparable as possible.

Vehicle-km and the vehicle fleet

The forecast of vehicle-km used in VDI/VDE/IT, IFV Köln (2005) is shown in the table below. The figures in the brackets refer to the annual growth from the previous reference year. It can be seen that total traffic is estimated to grow by an annual rate of 1.7% from 2002-2010 and 1.1% from 2010-2020. In comparison, the ICF study refers to a general traffic growth of 1.6% p.a. from 2003[13].

By comparison the vehicle fleet is estimated to grow by 1.5% p.a. from 2002-2010 and 0.9% p.a. from 2010 -2020, which is close to the estimated change in the vehicle-km.

Table 4-8 Vehicle-km forecast - VDI/VDE/IT, IFV Köln (2005) (Billion vehicle-km)

	2002	2010	2020
Passenger transport	2,601	2,956 (1.6%)	3,274 (1.0%)
Goods transport	568	667 (2.0%)	754 (1.2%)
Total	3,169	3,623 (1.7%)	4,028 (1.1%)

Source: VDI/VDE/IT, IFV Köln (2005)

Note: Figures in brackets refer to the annual growth from the previous reference year.

Change in crash and casualty rates, Do-nothing scenario

Improvements in the general safety of the vehicle fleet and safety improvements in the road infrastructure will lead to a decline in crash and casualty rates even if nothing extraordinary is done to promote the safety technologies under consideration here. This has been taken into account in this analysis.

The figures on the change in crash and casualty rates due to improved vehicles and roads used in the ICF study are shown in the table below.

[13] Special traffic growth estimates are applied for Greece, Portugal, Spain and Germany.

Table 4-9 Change in crash and casualty rates due to improved vehicles and roads - ICF (2003)

Member State	Crashes	Injuries	Fatalities
Greece	-3.0%	-3.0%	-2.5%
Portugal	-2.5%	-2.5%	-2.5%
Spain	-2.5%	-2.5%	-2.5%
Others (EU-15)	-1.5%	-1.5%	-2.0%

Source: ICF (2003)

The argument for applying higher rates for Greece, Spain and Portugal is that they are becoming more like the remaining member states (of EU-15) both in terms of their economies and road safety policies.

The numbers seem low compared to the historically observed development in road safety, as data shows that road safety in EU-15 has improved significantly over the last decade. The number of fatalities has been reduced by an annual rate of 3.3% in the same period when traffic has grown by 1.8%. Hence the improvement in terms of fatalities per billion vehicle-kilometres has been even larger, namely 5.1% p.a.[14].There has been a larger decline in the number of fatalities than in the number of accidents, as the safety performance of the existing fleet is better compared to previous vehicle generations. However, as it is uncertain whether this development can continue, the analysis presented here is based on the ICF figures for EU-15.

The figures used here are shown in the table below.

Table 4-10 Change in crash and casualty rates due to improved vehicles and roads

	Crashes	Severe injuries	Slight injuries	Fatalities
EU-15	-1.5%	-1.5%	-1.5%	-2.0%
New member states	-2.5%	-2.5%	-2.5%	-3.0%

Please note that the continuous increase in traffic partly offsets the expected decline in crash and casualty rates. The relationship between increases in traffic and accidents is dependent on road design, traffic volume and composition, etc. In this study, the assumed relationship between traffic growth and changes in accidents is presented in. The relationship is based on estimates presented in Transportøkonomisk Institutt (1997).

[14] VDI/VDE/IT, IFV Köln (2005)

Table 4-11 Relationship between traffic and accident changes

	Injury accidents	Fatal accidents
100% traffic growth	80% increase	25% increase

Source: Transportøkonomisk Institutt (1997)

Forecast
The resulting projection on the future number of fatalities and injuries are summarised in the table below.

Table 4-12 Projected number of future fatalities/injuries in selected years

	2002	2010	2020
Fatalities	49,686	42,382	34,797
Severe injuries	480,043	448,550	412,525
Slight injuries	4,730,451	4,429,204	4,083,271

4.4 Effects on accidents (step 4)

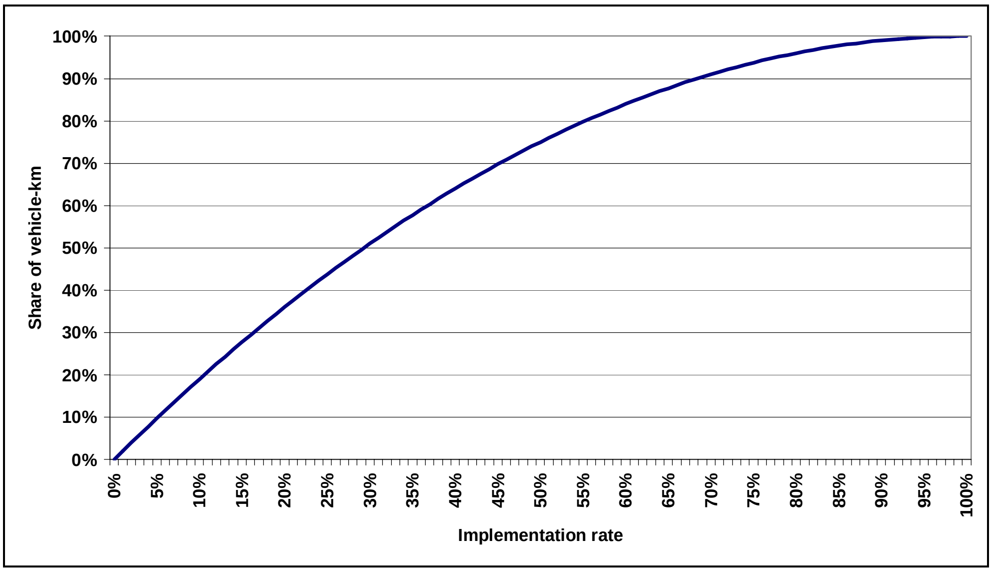
The level of road safety can be influenced by 3 main factors[15]:

1) The exposure in traffic
2) The crash risk at a given exposure
3) The consequences of a crash.

Exposure in traffic
The most direct measure of exposure is vehicle-kilometres travelled. In general safety equipment is of greatest benefit to those drivers with the highest vehicle-kilometres per year. To account for this, it is assumed that those drivers who install the techniques under consideration even when there are no legal requirements for doing so (Do-nothing scenario) are those drivers with the highest vehicle-kilometres per year. In VDI/VDE/IT, IFV Köln (2005) it is assumed that a 10% market diffusion will correspondingly affect 20% of vehicle-kilometres. A similar relationship is used in this study. The relationship used here is shown in the figure below.

[15] Distinction used by The European Transport Safety Council (ETSC).

Figure 9 Relationship between implementation rate and vehicle-km



Likewise, data shows that new cars drive more kilometres per year than old cars. This was also taken into account by assuming a similar relationship as shown above.

4.5 Data requirements

The data requirements are rather large for making the safety assessment as described above.

The required data for each of the technologies under consideration is described below. The required data for assessing the safety impacts of each technology are:

- Identification of relevant accidents
- The level of market deployment in Do-something in 2006 ("X" in Figure 8)
- The level of market deployment in end-of-appraisal year with no extra measures to accelerate the roll-out of the technology ("Y" in Figure 8)
- Change in collision probability (see Table 4-3)
- Change in accident severity (see Table 4-4)

Apart from the data for the safety assessment, cost data is also required (ref. chapter 5).

5 CBA approach (steps 5-7)

The framework for the economic cost-benefit assessment is described in this chapter.

First the general framework is described (sections 5.1-5.3). Then steps 5-7 of the seven-step approach are described (sections 5.4-5.6). Finally the main reservations to the results of the CBA are outlined in section 5.7.

5.1 Evaluation criteria[16]

To assess whether it is economically beneficial to implement a certain safety technology it is necessary to calculate the *net present value (NPV)* of the project. The net present value is the difference between the discounted stream of benefits and the required costs. If the net present value is greater than zero then the introduction of the safety system under consideration will be beneficial to society.

The net present value of the future cost (or benefit) streams can be expressed as:

$$\mathrm{NPV} = \sum_{t=0}^{T} NB_t \times \frac{1}{(1+r)^t}$$

where,

NPV	is the net present value of the stream of net benefits from year *t* to *T*
T	is the time horizon of the evaluation
NB_t	is the net benefits (benefits minus costs) incurred in year *t*
r	is the rate of discount.

An alternative to the NPV is the *benefit/cost-ratio (BCR)*, which is the present value of benefits divided by the present value of costs. When the BCR is greater than one, the present value of the project's benefits are greater than the present value costs. This means that the project also has a positive NPV, and consequently is considered beneficial to society.

[16] This section draws heavily on HEATCO (2005b).

The ranking of the safety technologies under consideration was made on the basis of the benefit/cost-ratio (BCR). However, this information is supplemented by information on the net present value (NPV).

5.2 Basic assumptions in this study

The basic underlying assumptions of the economic cost-benefit analysis are outlined in the table below.

Table 5-1 Basic assumptions

Parameter	Assumption/description
Time horizon	20 years (2006-2025)
Discount rate	5%
Result year	2005
Do-nothing scenario	Projection of number of fatalities and injuries
Do-something scenario	Estimate of the effect on the number of fatalities and injuries of implementing each of the safety technologies separately
Benefits	Primarily reduced number of fatalities, severe injuries and slight injuries

To summarise, the economic attractiveness of implementing a certain technology is evaluated for a 20-year stream of benefits (reduced fatalities/injuries) and costs. All costs and benefits are discounted to year 2005 with a 5% discount rate. The purpose of discounting is to express in present values the flow of costs and benefits involved in an appraisal period. Once the sets of future values are expressed in present values, they are comparable and can therefore be used to determine whether the overall welfare gain arising from the introduction of the safety technology under consideration is worth its costs.

5.3 Delimitation

Theoretically, all benefits and costs should be accounted for in a cost-benefit analysis. In practice, however, effects are left out either because the effects are considered to be of minor importance, due to difficulties of estimating a trustworthy money value or due to difficulties of quantifying the effects. In this way, a cost-benefit analysis only reflects a stylised picture of reality.

The focus in this study is on what is considered the main effects of implementing new safety devices in vehicles:

- Safety effects, i.e. the estimated impact on the number of fatalities/injuries of implementing the technology.
- Costs of implementing technology in the vehicles under consideration.

In addition, the analysis indirectly takes into account the indirect costs of an accident in form of congestion, as average congestion costs are included in the unit values used (see section 5.4).

5.4 Net benefits/unit costs of accidents (step 5)

The economic net benefits are evaluated by assessing the accident costs for the Do-something scenario and the accident costs for the Do-nothing scenario. Accident costs are estimated on the basis of standard unit costs for accidents. The net benefits of implementing the system are compared to the cost of implementing the system.

The problem is that whereas the costs of implementing the new technology in the vehicles are expressed in monetary terms, the benefits of reduced accidents, fatalities and injuries are not "traded goods" and do as such not have a direct monetary value.

Hence, to assess the benefits of improving road safety for the CBA, it is necessary to estimate the money value per reduced fatality/ injury. The derivation of such figures is however not a simple task.

The unit costs of accidents used here are derived below by first evaluating the current practice in EU member states (section 5.4.1) and a discussion on whether to use country specific values or EU averaged values (section 5.4.2). The unit costs applied in this study are presented in section 5.4.3.

5.4.1 Current practice in EU member states

The values applied in the national frameworks for infrastructure project appraisal vary considerably across countries.

Recent evidence[17] shows that the values used for a fatality lie between approx. €200,000 and approx. €1,650,000 and that there are clear differences to be observed between the different regions.

In the north/west region of the EU, all countries except Denmark use values which are above €1,100,000 per fatality. In contrast, in the east the values lie between €210,000 and €840,000, averaging approx. €540,000 – less than half of the average in the north/west region. In the southern countries the values are even lower, with an average of €330,000.

For serious injuries the differences between north/west, east and south are even larger than for fatalities. In the north/west region, the average of approx. €150,000 is 4 times larger than the average in the east of €38,000, which is more than twice as high as the value used in for example Portugal. Within the north/west region of the EU, the values for a serious injury vary between

[17] HEATCO (2005b) in € 2002, factor prices.

€67,000 and €227,000. In contrast, all values used in the east and south regions are lower, the lowest being the value used in Portugal.

For slight injuries the values are much lower, sometimes less than one tenth of the value for serious injuries. Again, the same picture is observed, namely relatively high values in the north/west (on average €18,100, but varying widely between €3,400 and €36,600), but much lower values in the east and south (on average €3,000 in the east and €1,000 in Portugal).

5.4.2 Country specific values or EU-averaged values?

The significant differences in the values used for the countries in the EU raise the question of whether to use country specific values or EU-averaged values.

The main advantages and disadvantages of using the two different approaches are outlined below[18].

The main advantage of using country-specific values is that such an approach is more 'satisfactory' in relation to the neo-classical basis for economic cost-benefit analysis, i.e. that economic values should be derived from the expression of individuals' preferences in the form of their willingness to pay in monetary terms. In addition, a practical advantage might be that the results of the CBA will be more acceptable and easier to understand for domestic stakeholders when the values used derive directly from the national context. Possible disadvantages of using country-specific values are e.g. that specific unit values may not exist or be of poor quality for individual countries within the EU, and that the valuation of identical impacts using different local values may be considered to be morally indefensible. For example, differences in the values of reduced fatalities between countries may not be acceptable to decision-makers.

The advantages of using EU-averaged values are e.g. that a set of common EU values for individual impacts might simplify the appraisal process and increase transparency. Furthermore, it may be more politically acceptable on the basis of perceived equity. The main disadvantage is that this approach does not fully reflect differing preferences and resource costs. In addition, the use of EU-averaged values is in conflict with the values which are supplied in some countries by national level ministries.

Given the scope of this study, the lack of good quality data covering all member states and concerns over the political acceptability of the results, this analysis is based on EU-averaged values.

5.4.3 Unit costs applied in this study

The next issue is to decide which values to use based on EU-averaged values. It is outside the scope of this analysis to come up with new data on this. Hence

[18] This section draws heavily on HEATCO (2005c).

the cost figures per accident impact used were collected from other international studies/sources.

The table below shows the unit cost rates applied in the Directive 1999/62/EC Annex III for fatalities, serious injuries and slight injuries.

Table 5-2 Personal damage cost rates - Directive 1999/62/EC Annex III

	€/fatality or injury
Fatality	1,000,000
Severe injury	135,000
Slight injury	15,000

It appears that these values are well inside the range of values used in the EU member states for infrastructure appraisal (see table below). Furthermore, the same figures were used in VDI/VDE/IT, IFV Köln (2005).

Table 5-3 Unit costs per fatality, injury or damage only accident - EU country practice (in €, 2002-prices/values)

Crash severity	Range of values used
Fatality	200,000-1,650,000
Serious injury	15,000-220,000
Slight injury	1,000-37,000

Note: Figures are only indicative

Source: HEATCO (2005b)

Each accident with personal injuries is accompanied by property damage and most likely also congestion (leading to time losses, higher fuel consumption, air pollution and carbon-dioxide emissions).

For property damage, evidence presented in VDI/VDE/IT, IFV Köln (2005) indicates that these costs are in the region of €1,500 to €30,000 per accident in the north/west region of the EU. In VDI/VDE/IT, IFV Köln (2005) it is assumed that property damage costs are €6,000/accident.

For congestion costs figures are most often differentiated for the severity of the accidents, as the average duration of a fatality crash is higher than the average duration of crashes with severe or slight injuries. In VDI/VDE/IT, IFV Köln (2005) it is assumed that average unit costs for congestion are €15,000/accident for accidents with fatalities, and €5,000 for accidents with personal injuries.

This study uses the figures presented in Table 5-2 for personal damage and the unit costs for congestion and property damage used in VDI/VDE/IT, IFV Köln (2005). However, as congestion costs and property damage costs only play a minor role (cost figures are low compared to personal damage), it has been decided for reasons of simplicity to convert them into "per person killed/injured" instead of for "per accident". This is considered to have an insignificant impact on the results.

The conversion factors presented in ICF (2003) are used for this purpose. This data suggests that there are typically 1.36 injuries per injury-causing crash and 1.15 fatalities per fatal crash.

The resulting unit costs for the main analysis are presented in Table 5-4 below.

Table 5-4 Applied unit values - Accidents (€/fatality or injury)

	Casualties	Property damage	Congestion	Total
Fatalities	1,000,000	5,200	13,000	1,018,200
Severe injury	135,000	4,400	3,700	143,100
Slight injury	15,000	4,400	3,700	23,100

Note: Rounded figures. Figures are assumed to be constant over time.

Safety technologies do not only influence the risk of accidents, but also the severity of accidents. The value of reducing the severity can be derived from the table above. For example, the value of reducing the impact from fatal to severe injury is €875,100 Euro (€1,018,200-€143,100).

5.5 Cost assessment (step 6)

The costs of implementing, operating and maintaining the safety system under consideration are assessed in step 6. Most often the investment costs are the most important cost element, and most often it is the only cost estimate which is available from existing studies.

It should be noted that the costs of the technologies tend to decrease over time which could make some of the currently least cost-effective measures cost-effective in the future.

5.6 Economic cost-benefit assessment (Step 7)

In the final step, it is assessed whether it is economically beneficial to implement the safety technology under consideration.

The net benefits of the system calculated in step 5 are compared to the net costs of implementing the system (step 6). If net benefits outweigh net costs, the introduction of the safety system will be beneficial to society.

As mentioned in section 5.1, the ranking of the safety technologies under consideration was made on the basis of the benefit/cost-ratio (BCR).

5.7 Reservations

Cost-benefit analysis is the preferred method for evaluating the economic performance of new vehicle technologies for society. However, there are a number of issues which indicate that the results of a economic cost-benefit analysis should not be considered as the only necessary information for decision-makers considering whether to promote a certain technology or not.

The 3 main reservations are related to:

- Effects which are not monetised
- Uncertainty
- Distributional effects

Effects which are not monetised
The implementation of new safety technologies in vehicles may have a number of effects. As mentioned in section 5.3, the focus here is on safety effects, operating costs and the costs of implementing technology in the vehicles under consideration. Furthermore, congestion costs are implicitly included in the cost-benefit assessment.

Other possible effects of implementing new safety technology in vehicles, which are (normally) not accounted for, include:

- Vehicle operating costs
- Competitiveness of the European car industry
- Effects on the environment
- Customer satisfaction with the safety system
- Affordability
- No. of stakeholders involved
- Issues of implementation
- The possibilities of by-passing the system
- Maturity of the technology

Furthermore, the analysis only focuses on accidents with fatalities and/or injuries, i.e. damage only accidents are disregarded. It is not possible to assess how this affects the results, as it depends on the specific case (dependent on the severity distribution of accidents). However, the effect of disregarding damage only accidents on the results is considered to be relatively small.

Finally, obstacles to implementation and possibilities of by-passing the systems should be taken into account.

Uncertainty
Furthermore it is import to realise that the future outcome of a project is not known with certainty. This is the case here for all the main elements of the CBA, i.e. implementation costs, operation costs and the effects on accidents.

It is therefore an integrated part of a CBA to assess the robustness of the results. The robustness of the results (both the individual assessment of economic performance and the ranking of initiatives) is here evaluated by partial sensitivity analyses.

Furthermore, it must be borne in mind that the CBA assessment must cope with data limitations which affect the accuracy of the calculations.

Distributional effects
Finally, it is important to keep in mind that the CBA does not take into account how a project affects different groups (some win and some lose), which might be an important issue for the decision-maker.

In summary, the reservations described above mean that the results of a cost-benefit assessment should not stand alone, but should be supplemented by additional information. These issues must be taken into account before it is decided to promote the use of a certain technology.

6 Technology 1.1: Electronic stability control (ESC)

6.1 Definition of technology

Electronic stability control (ESC) can be described as follows:

ESC stabilises the vehicle under all driving conditions and driving situations within the physical limits. The system helps to stabilise the vehicle and prevent skidding when cornering or driving off through active brake intervention on one or more wheels and intelligent torque management[19].

Electronic stability control (ESC) is also referred to as electronic stability program (ESP). Electronic stability control (ESC) is however used here, as electronic stability program (ESP) is a registered trademark of Robert Bosch GmbH.

6.2 Accidents - Do-nothing scenario

ESC mainly affects single accidents and loss of control accidents on wet and slippery roads[20].

However, as will be clear from section 6.5, the estimated effect of ESC is estimated on the basis of total accidents.

6.3 Scenario for implementation

ESC has been in serial production for 10 years. However, due to relatively high costs the technology is mostly applied in high-class cars. Most experts however agree that market penetration will grow over the coming years.

In eSafety Forum Working Group (2005) it is estimated that the market penetration rate for ESC in the "business as usual" scenario is "medium" (20%-50% of new cars equipped) in 2005 and "high" (50%-80%) in 2010 and 2020.

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[19] Based on eSafety Forum Working Group (2005)

[20] eSafety Forum Working Group (2005)

The estimates seem reasonable when taking into account the data provided in Bosch (2005a) on the ESC installation rates in new cars in Europe. This data is shown in Table 6-1.

Table 6-1 ESC installation rates in new cars in Europe

Country/Region	Installation rate in new cars
Europe (2002, 2003, 2004)	24%, 29%, 37%
Italy	24%
UK	29%
Spain	32%
France	39%
Germany	67%

Source: Bosch (2005a)

This analysis is based on the assumption that 9% of the cars (share of existing fleet and not the share of new vehicles which the above mentioned figures refer to) have ESC installed in 2006 (see table below). Similar figures are found in Bosch (2005a) and eSafety Forum Working Group (2005).

Furthermore, this analysis is - in line with most others - based on the assumption that this ratio will increase over the coming years even if nothing extraordinary is done to promote ESC. As can be seen in the table below, it is assumed that 50% of all cars will have the technology installed in end-of-appraisal year 2025. This corresponds to the estimated increase in the "business-as-usual scenario" of the e-Safety Forum Working Group (2005) mentioned above and one scenario presented in Bosch (2005a).

Table 6-2 Market penetration - Electronic stability control (ESC)

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	9%	50%
Do-something	9%	100%

Source: Own estimates based on Bosch (2005a) and eSafety Forum Working Group (2005)

Sensitivity analyses are made for a market deployment rate of 25% (low) and 75% (high) in 2025 for the Do-nothing scenario.

6.4 Cost assessment

The costs of implementing ESC in new cars are relatively low, as costs have declined by up to 75% over the last 10 years during which ESC has been in serial production[21] and because ESC is based on ABS, which will be installed in all new cars in EU-25 as from July 2006. Whereas the ABS identifies any ten-

[21] eSafety Forum Working Group (2005)

dency of a wheel to lock and regulates the breaking pressure to prevent this, ESC uses additional sensors that enable the electronic control unit to compare the driving condition called by the driver with the vehicle's actual dynamic condition.

In the US, ESC is offered as an option to Volkswagen models at a cost of $280 or €240. For other car makers prices appear to be slightly higher[22].

The cost-benefit assessment presented here is based on the assumption that ESC costs €250 per vehicle. As the cost estimates are rather uncertain, sensitivity analyses are made for unit costs of €150 and €500

6.5 Safety impacts

The evidence from existing studies on the safety impacts of ESC is summarised below, before the figures used here are presented.

Existing studies

Several studies have considered the safety impacts of ESC. The results of some of the most important studies are summarised below[23].

In a study of accidents in Sweden, Lie et al (2005) show that the overall effectiveness on all injury crashes was 16.7% (+/- 9.3%), while for serious and fatal crashes the effectiveness was 21.6% (+/- 12.8%)[24]. The estimates are based on the assumption that rear end crashes on dry road surfaces are not affected at all by ESC.

A study from the United States[25], which compared per vehicle crash involvement rates for otherwise identical vehicle models with and without ESC systems, confirms the results of Lie et al (2005): that the system can reduce the number of accidents significantly, and that crashes with fatal injuries are reduced to a greater extent than less severe crashes. Furthermore, ESC was found to affect single-vehicle crashes to a greater extent than multiple-vehicle crashes. ESC reduced single-vehicle crash involvement risk by approximately 41% and single-vehicle injury crash involvement risk by 41%. This translates to an estimated 7% reduction in overall crash involvement risk and a 9% reduction in overall injury crash involvement risk. Likewise, ESC was found to have reduced single-vehicle fatal crash involvement risk by 56 percent, which translates to an estimated 34 percent reduction in overall fatal crash involvement risk.

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[22] http://money.cnn.com/2003/09/25/pf/autos/who_has_esc/ and Electronic Stability Control Coalition [http://www.esceducation.org/about_esc/faqs.shtml#faq4]

[23] Based on eSafety Forum Working Group (2005) and original references

[24] The effectiveness for serious and fatal crashes on wet roads was 56.2 (+/- 23.5%). On roads covered with ice and snow, the corresponding effectiveness was 49.2 (+/- 30.2%).

[25] Farmer (2004)

Another study from the United States[26] compared specific models of passenger cars and SUVs with ESC as standard equipment versus earlier versions of the same make/models, using multi-vehicle crash involvements as a control group. Dang (2004) found that single vehicle crashes were reduced by 35% in passenger cars and by 67% in SUV crashes. The study also showed significant or almost significant reductions in the multi-vehicle crash rates. The statistical method used entails that the true effectiveness of ESC could be even higher that the figures reported above[27].

Different car manufactures have also investigated the impacts of ESC. Some of the results are summarised in the table below. These results confirm the results of the studies mentioned above, although the results seem to be in the high end of the range.

Table 6-3 Car manufacturers' estimate of the impacts of ESC

Car manufacturer	Accident category	Effectiveness of ESC
Toyota	All-single accidents	-35%
	Severe accidents	-50%
DaimlerChrysler	Accidents	-42%
Volkswagen	Fatalities	-35%
Ford	Accidents	-35%

Source: Bosch (2005a)

Finally, Langwieder (2005) has compared all available scientific studies on the impacts of ESC. On the basis of this, Langwieder (2005) finds that a 100% equipment of all cars with ESC could reduce the number of accidents with car occupant injuries by approx. 7 -11%. The reduction in car occupant fatalities would be approximately 15 -20%.

Estimates used in this analysis

The input to this analysis is shown in the tables below. Table 6-4 shows the change in collision probability.

The main analysis is based on the assumption that ESC leads to an estimated 17.5% reduction in overall fatal crash involvement risk, and a 15% reduction in overall injury crash involvement risk (equal for severe and slight, as there is no information on the split between accident types).

26 Dang (2004)

27 See e-Safety Forum Working Group (2005) for discussion

Table 6-4 Reduction in collision probability - Electronic stability control (ESC)

Fatalities	17.5% (7-35%)
Severe injuries	15% (7%-25%)
Slight injuries	15% (7%-25%)

Note: Figures in brackets are the figures used as min/max-values in the sensitivity analyses

It could be argued that ESC also reduces the severity of accidents if they occur due to lower collision speed. This effect is not taken into account here, i.e. it is assumed that ESC has no effect on accident severity if an accident occurs.

6.6 Accidents - Do-something scenario

The effect on the number of fatalities, severe injuries and slight injures of installing ESC in all new vehicles is presented in the table below.

It is, for example, estimated that ESC can save approx. 2,250 lives in 2020 if it is made mandatory in all new vehicles.

Table 6-5 Study estimate of the effect of ESC in selected years

Category	2010	2020
Fatalities	-2,138	-2,250
Severe injuries	-19,396	-22,866
Slight injuries	-191,530	-226,337

Source: Own estimates

In comparison, the estimate of the eSafety Forum Working Group (2005) of the benefits of ESC installed after 2005 is shown in the table below.

The estimates of the eSafety Forum Working Group (2005) are based on the following assumptions:

- Market penetration for "business as usual" is 24.5% in 2010 and 51.5% in 2020
- Market penetration for "eSafety Implementation Road Map case" is 30% in 2010 and 73% in 2020
- The effect of ESC is 15-20% on all road fatalities involving equipped cars.
- The expected number of fatalities without additional eSafety measures is 37,000 in 2010 and 28,000 in 2020 for EU25.

Table 6-6 eSafety estimate of the benefits of ESC - fatalities

Year	Business as usual	eSafety Implementation Road map	Effect on fatalities
2010	850-1,150	1,150-1,550	approx. 400
2020	2,000-2,700	2,900-3,900	approx. 1,000

Source: eSafety Forum Working Group (2005)

The difference in the estimated number of fatalities saved is solely a result of the fact that the Do-something scenario analysed here is more "ambitious" (higher market penetration) than the "eSafety Implementation Road Map". When correcting for this the results are very similar.

6.7 Cost-benefit assessment

The result of the cost-benefit assessment for ESC is shown in the table below. It can be seen that benefits are estimated to exceed costs by a factor 3.8.

Table 6-7 Main results of CBA - Electronic stability control

Category	Net present value in 2005, million €
Accident costs	**112,138**
Fatalities	24,890
Severe injuries	33,609
Slight injuries	53,639
Total costs	**-29,642**
Total net present value	**82,496**
Benefit/cost-ratio	**3.8**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

The values used for key parameters in the economic cost-benefit calculations presented above are, as mentioned, uncertain.

The robustness of the results to the values used is therefore evaluated. The results of selected sensitivity analyses are shown in the table below.

Table 6-8 Results of sensitivity analyses - Electronic stability control (ESC)

Sensitivity analysis	BCR
1. Low unit costs (€150)	6.3
2. High unit costs (€500)	1.9
3. Low effect on collision probability (see section 6.5)	1.7
4. High effect on collision probability (see section 6.5)	6.6
5. Low market penetration rate in 2025 (25%)	4.1
6. High market penetration rate in 2025 (75%)	3.7
7. Low average lifetime of vehicle (12 years)	3.4
8. High average lifetime of vehicle (16 years)	4.1

For all the values used in the sensitivity analyses, benefits exceed costs. However, the estimated benefit/cost-ratio is very sensitive to the unit costs and the safety effect. The results are robust regarding assumptions about the market penetration rate in 2025 for the Do-nothing scenario and the assumed lifetime of the vehicle.

7 Technology 1.2: Brake assist system (BAS)

7.1 Definition of technology

The brake assist system (BAS) can be described as follows:

"Brake assist is a function that interprets the manner in which a driver presses the brake pedal and if it is computed to be in a manner typical of responding to an emergency situation, the vehicle will apply more braking than the force on the brake pedal would dictate alone. Through this assistance the available braking of the vehicle, including Anti-lock braking system (ABS) engagement, can be used to a greater extent than perhaps the driver was aware was possible. These systems support the driver and lead to reduced collision speed, or help to avoid the potentially occurring accident altogether since evasive driving manoeuvres can be performed more easily once the speed is reduced more effectively. The efficiency of Brake assist systems (BAS) is related to hesitant braking performance of drivers in real world situations[28]."

Bosch (2005b) indicates that the system is also available with long range radar.

7.2 Accidents - Do-nothing scenario

Brake assist systems are targeted at reducing the risk of rear end and head on collisions, merging and intersection collisions, vehicle-pedestrian collisions, collisions with obstacles and left roadway accidents[29].

The main target of brake assist systems is the vulnerable road users who are hit because of insufficient braking forces. Annually approx. 12,000-13,000 pedestrians and cyclists are killed and up to 300,000 severely injured[30]. Brake assist systems also reduce fatalities and injuries in vehicle to vehicle accidents by shortening braking distances and reducing impact energy.

[28] TRL (2004, page 52-53)

[29] VDI/VDE/IT, IFV Köln (2005, page 26)

[30] TRL (2004, page 183-185)

In e.g. Germany (see Table 7-1), the distribution of accidents shows that 68% of reported accidents are relevant for BAS, 87% if accidents with lane departures are included, as suggested in VDI/VDE/IT, IFV Köln (2005).

Table 7-1 Causes of accidents in Germany within and outside of built-up areas (2002)

Type of accidents	Rear end collision	Frontal collision	Lateral collision	Pedestrian collision	Collision with obstacle	Lane departure	Lane change	Other	Total
Share of accidents	21%	8%	31%	7%	1%	19%	4%	9%	100%

Source: Bosch (2005b)

Corresponding statistics for Denmark show that BAS can be relevant for all main types of registered accidents involving motor vehicles (if including single left roadway accidents). Cars, trucks and buses were e.g. involved in 76%, 6% and 3% of all reported accidents in 2002[31].

Table 7-2 Causes of accidents in Denmark within and outside built-up areas (2002)

Type of accidents	Single accident	Rear end collision	Frontal collision	Lateral collision (on same road)	Lateral collision (on crossing roads)	Collision with parked vehicle	Pedestrian collision	Collision with obstacle	Total
Share of accidents	22%	12%	8%	20%	21%	3%	12%	1%	100%
Share of fatalities	29%	13%	18%	11%	13%	1%	13%	2%	100%

Source: Danmarks Statistik (2003)

SAFETYNET (2005) shows that approximately 35% of fatalities registered in 11 of the EU-15 countries occur in rear end or head on collisions, etc. while another 23% happen in lateral (side) collisions. Approximately 40% are registered as single accidents.

In another source it is stated that brake assist control can be relevant in 30-60% of all accidents[32]. Bosch asserts that drivers in more than 50% of all accidents do not brake at all, due primarily to inattention. In more than 45% of accidents drivers make a partial braking, mainly due to inexperience. Only in 1% of accidents is a full breaking performed[33]. A Volkswagen study analogously claims that in severe accidents, approx. 85% of drivers either do not brake at all or not to the full possible deceleration[34].

[31] Danmarks Statistik (2003, page 17-21)

[32] CARS21 (2005a, page 2)

[33] Bosch (2005b)

[34] eSafety Forum Working Group (2002, page 24)

Brake assistants are only meaningful in those accidents in which the driver actually brakes[35].

Based on the above information it is estimated that BAS can influence up to 50% of all road fatalities and injuries in EU-25 (see Table 7-3).

Table 7-3 Share of injuries in relevant accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-15	50%	50%	50%
NMS	50%	50%	50%

7.3 Scenario for implementation

In VDI/VDE/IT, IFV Köln (2005) it is stated that braking assistance was introduced in 2003 as a standard function for selected vehicle models. Other sources mention that the system was introduced as early as 1996[36]. Based on a voluntary agreement with the automotive industry, all vehicles under consideration in EU-25 will be fitted with anti-lock braking systems (ABS) in July 2006. The addition of BAS, which requires ABS, is considered to be of little extra cost.

3.8% of the Spanish car fleet had brake assist system/chassis stability control at the end of 2003[37].

It is therefore estimated in this study that market penetration in 2006 will be approx. 5%, while the diffusion in the end-of-appraisal year 2025 will be 20% of all cars in the "business-as-usual" scenario.

Table 7-4 Market penetration - Brake assist system (BAS)

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	5%	20%
Do-something	5%	100%

Sensitivity analyses are made for a market deployment rate of 10% (low) and 50% (high) in 2025 for the Do-nothing scenario.

[35] Hannawald (unknown)

[36] VDA (2005, page 156)

[37] Indicated during stakeholder consultations

7.4 Cost assessment

It has not been possible to obtain any solid estimates of the cost of BAS. Hence the break-even unit costs have been estimated (see section 7.7).

7.5 Safety impacts

A stakeholder claims that BAS can reduce all pedestrian fatalities by 5.8% and all pedestrian severe injuries by 5.7%. Other sources claim higher effects. Thus the German Automobile Industry, VDA (2005), states that investigations with driving simulators have shown that 45% of all collisions with pedestrians, in which the driver applies the brakes, can be avoided with a brake assistant installed.

If the collision - with e.g. a pedestrian - can not altogether be avoided, then at least the speed at collision can be greatly reduced. Fatalities or severe injuries in collisions can be reduced by more than 10% according to VDA (2005).

If all vehicles are equipped with a brake assistant causing full braking 30 m earlier, the potential for reduction in fatalities in Germany is given at 450, or 7% of the grand total of 6,842 (in 2002). 250 of these can be saved through collision avoidance and 200 through collision mitigation. Collision avoidance could save a further 3,000 severe and 20,000 slight injuries annually in Germany. This corresponds to approx. 3-5% of the total injuries in Germany in 2002. Correspondingly, collision mitigation due to brake assistants influences a minimum of 30% of accidents and could save 2,500 severe and 13,000 slight injuries, corresponding to approximately 3% of total injuries according to Bosch. The value of reduced material damage must be added to this[38].

Given that brake assistants are only estimated to influence 50% of total accidents, the unit effect is estimated to be approximately the double of the above potential for all accidents from Bosch.

The effects used in this study are presented in Table 7-5 and Table 7-6.

Table 7-5 Reduction in collision probability - Brake assist systems (BAS)

Fatalities	8% (4%-16%)
Severe injuries	8% (4%-16%)
Slight injuries	8% (4%-16%)

Note: Figures in brackets are the min/max values used in the sensitivity analyses.

Supplementing the estimated impact on accident risk, the brake assistant - according to Bosch (2005b) - is also expected to mitigate accident consequences by reducing the severity of injuries by one class.

[38] Bosch (2005b) and Bosch (2005c)

Table 7-6 Accident severity matrix - Brake assist systems (BAS)

Before	After Fatalities	Severe injuries	Slight injuries	Avoided
Fatalities changing to…		6% (3%-12%)	0%	0%
Severe injuries changing to…	0%		6% (3%-12%)	0%
Slight injuries changing to…	0%	0%		6% (3%-12%)

Note 1: From a statistical point of view the reduction in severity will not always shift down one severity class, i.e. the indication of 0% represents a simplification.
Note 2: Figures in brackets are the min/max values used in the sensitivity analyses.

7.6 Accidents - Do-something scenario

The effects of BAS on the number of fatalities and injuries are summarised in Table 7-7.

Brake assist systems are estimated to reduce the potential and severity of accidents by facilitating earlier braking and reducing impact consequences. It is estimated in this study that EU implementation of brake assistants can save 1,223 lives in 2010 and 1,675 lives in 2020, when all vehicles have the required equipment installed. Corresponding figures for reductions in severe and slight injuries appear in the table below.

Table 7-7 Study estimate of the effect of Brake assist systems (BAS) in selected years

Category	2010	2020
Fatalities	-1,223	-1,675
Severe injuries	-12,431	-19,164
Slight injuries	-122,383	-188,332

7.7 Cost-benefit assessment

The net present value of the net benefits of promoting the use of BAS is presented in the table below. This benefit/cost-ratio can however not be estimated, due to a lack of solid cost estimates.

Table 7-8 Main results of CBA - Brake assist systems

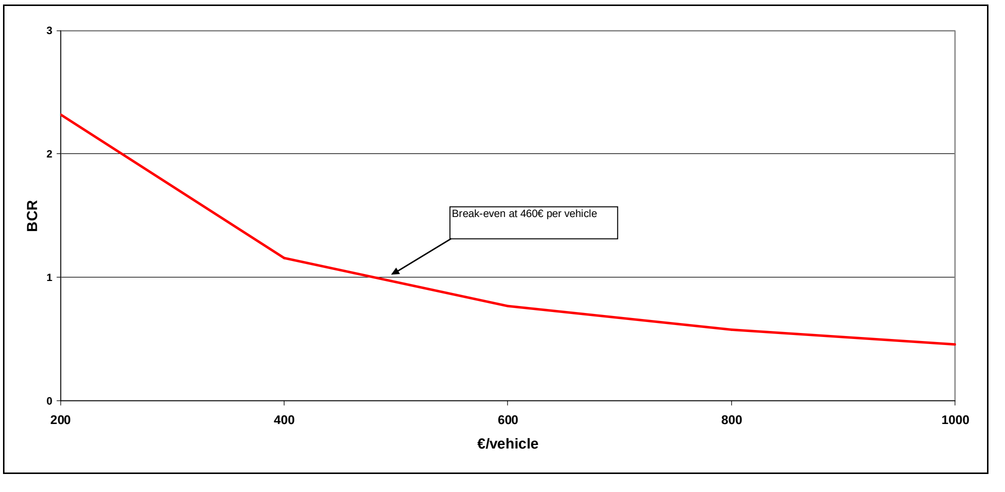
Category	Net present value in 2005, million €
Accident costs	**80,885**
Fatalities	16,316
Severe injuries	24,954
Slight injuries	39,616
Total costs (Unit related)	**?**
Total net present value	**?**
Benefit/cost-ratio	**?**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

As no solid cost estimates are available, the benefit/cost ratio has been estimated for a range of unit costs. The result is presented in the figure below. It can for example be seen that the benefit/cost-ratio would be 2.3 if the cost of implementing BAS was €200 per vehicle.

The break-even costs (i.e. the costs for which the benefit/cost-ratio is 1) are estimated at €460 per vehicle. If actual costs are lower, it is cost-effective to install BAS in all new vehicles in EU-25.

Figure 10 Benefit/cost-ratio depending on unit costs per vehicle



The robustness of the results (i.e. the estimated break-even unit cost) to the values used has been evaluated. The results of selected sensitivity analyses are shown in the table below.

Table 7-9 Results of sensitivity analyses - Brake assist system (BAS)

Sensitivity analysis	Break-even unit costs (€/vehicle)
1. Low effect on collision probability/accident severity (see section7.5)	235
2. High effect on collision probability/accident severity (see section 7.5)	910
3. Low market penetration rate in 2025 (see section 7.3)	480
4. High market penetration rate in 2025 (see section 7.3)	420
5. Low average lifetime of vehicle (12 years)	420
6. High average lifetime of vehicle (16 years)	500

It can be seen that the estimated effectiveness of the technology has a large impact on the estimated break-even unit costs, whereas the market penetration rate for 2025 and the assumed lifetime of the vehicle is of minor importance.

8 Technology 1.3: Improved vehicle compatibility

8.1 Definition of technology

Improved vehicle compatibility can be described as follows:

Improved vehicle compatibility is the changing the design of the vehicle to reduce the consequences of a collision between road users.

Here the analysis of improved vehicle compatibility is limited to collisions between cars and vulnerable road users; i.e. pedestrians and cyclists. Further, the analysis focuses on the impact of accidents in which pedestrians and cyclists are hit by the front of a passenger car. This accident type makes up most of the vehicle-pedestrian/cyclist collisions according to ETSC (2005).

The European Enhanced Vehicle-safety Committee (EEVC) has developed a series of tests to assess the injuriousness of the fronts of passenger cars. These are used to evaluate the bumper, the leading bonnet edge and bonnet top in respect of the level of injury reduction achieved by their design. The test methods are continuously developed.

In this study improved car fronts are defined as car fronts which comply with the EEVC standards in relation to for example low stiffness of the car front and ideal energy absorption (both in correlation to materials and the car design).[39]

8.2 Accidents - Do-nothing scenario

Improved vehicle compatibility is - as defined in this study - targeted at reducing the severity of collisions between cars and the vulnerable road users. The system only influences the consequences of accidents in which pedestrians and cyclists collide with the car front.

Improved vehicle compatibility does not prevent accidents, nor in principle the severity of vehicle-vehicle collisions.

[39] Matra (2005, page 8-10) and ETSC (2005, page 39-40)

TRL (2004) estimates - on the basis of CARE statistics - that close to 9,000 pedestrians are killed per year in EU-25. Of these, 60% are hit by a car front. The corresponding figures for cyclists are 3,400 and 44%. This indicates that approx. 7,000 pedestrians/cyclists are killed annually in EU-25 by being hit by a car front. This equals approx. 14% of all fatalities in EU-25.

Correspondingly, TRL (2004) estimates that 75,000-175,000 pedestrians and 49,000-115,000 cyclists are severely injured per year in EU-25. It is estimated that 56% of the severely injured pedestrians are hit by a car front and 45% of the cyclists are hit by a car front. Hence 13%-31% of all severe injuries are due to pedestrians/cyclists being hit by a car front.

No data is available for slight injuries.

This analysis is based on the data provided in the table below. The data has not allowed any meaningful distinction between EU-15 and new member states nor between severe and slight injuries.

Table 8-1 Share of injuries in relevant accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-15	17%	17%	14%
NMS	17%	17%	14%

8.3 Scenario for implementation

The European, the Japanese and the Korean union of car manufactures have agreed on using some or all of the EEVC standards in the future. The goal is in 2010, after further research, to have a number of standards implemented in 80% of the new cars. After 2012 the goal is that 100% of the new cars meet the standards which the car manufactures and the EU has agreed on[40].

The EU is already making progress in making car fronts safer for the vulnerable road users. It is not finally determined, however, how this will be done or when standards should be implemented.

It is assumed in this study that in 2025, approx. 50% of the car fleet will have car fronts that meet all standards prepared by EEVC.

The analysis made by the EEVC determines that only few cars today fulfil the current proposals for standards made by the EEVC[41].

[40] ETSC (2005)
[41] ETSC (2005)

Table 8-2 Share of market penetration for improved car fronts

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	0%	50%
Do-something	0%	100%

Sensitivity analyses are made for a market deployment rate of 25% (low) and 75% (high) in 2025 for the Do-nothing scenario.

8.4 Cost assessment

The improvement of car fronts will require several small initiatives. It has not been possible to obtain any solid estimates on the costs of adjusting car fronts. Hence, instead of calculating the benefit/cost-ratio, the break-even costs are calculated. In general it is expected that costs are very low, as the issue of improved vehicle compatibility is mainly a question of design processes.

8.5 Safety impacts

Improved vehicle compatibility does not affect the risk of collision, but only the severity of the accidents if a collision occurs.

According to the ETSC (2005), 20% of all fatalities and severe injuries among pedestrians and cyclists in EU-15 could be avoided if all cars were designed to pass the EEVC tests.

The European Commission (2003) analogously estimates that approx. 2,000 pedestrian and cyclist fatalities could be avoided if car fronts met EEVC standards in EU-25. This corresponds to approx. 16 % of all fatalities among vulnerable road users and an effectiveness rate of 28% (2,000 of 7,000 vulnerable road users killed in collisions with car fronts per year).

Based on the above information, the effect of improved vehicle compatibility is estimated as presented in the table below.

Table 8-3 Accident severity matrix - Improved vehicle compatibility

Before	After Fatalities	Severe injuries	Slight injuries	Avoided
Fatalities changing to…		28% (14%-40%)	0%	0%
Severe injuries changing to…	0%		28% (14%-40%)	0%
Slight injuries changing to…	0%	0%		28% (14%-40%)

Note 1: From a statistical point of view the reduction in severity will not always shift down one severity class, i.e. the indication of 0% represents a simplification.
Note 2: Figures in brackets are the min/max values used in the sensitivity analyses.

8.6 Accidents - Do-something scenario

The effect on the number of fatalities, severe injuries and slight injuries are presented in the table below. As can be seen, it is estimated that the improved vehicle compatibility in all new cars can save approx. 550 lives per year in EU-25.

Table 8-4 Study estimate of the effect of improved vehicle compatibility in selected years

Category	2010	2020
Fatalities	-547	-544
Severe injuries	-6,486	-7,289
Slight injuries	-62,412	-69,697

8.7 Cost-benefit assessment

The net present value of the net benefits of promoting improved vehicle compatibility is presented in the table below. The benefit/cost-ratio can, however, not be estimated, due to a lack of solid cost estimates.

Table 8-5 Main results of CBA - Improved vehicle compatibility

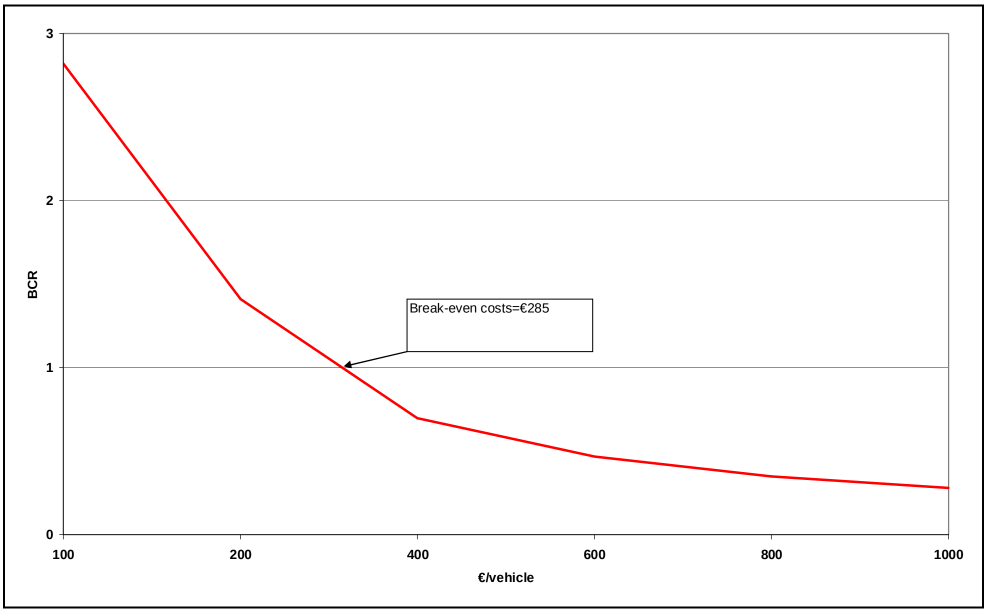
Category	**Net present value in 2005, million €**
Accident costs	**34,159**
Fatalities	6,201
Severe injuries	10,971
Slight injuries	16,988
Total costs (Unit related)	**?**
Total net present value	**?**
Benefit/cost-ratio	**?**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

As no solid cost estimates are available, the benefit/cost ratio has been estimated for a range of unit costs. The result is presented in the figure below. It can for example be seen that the benefit/cost-ratio would be 2.8 if the cost of implementing improved vehicle compatibility was €100 per vehicle.

The break-even costs (i.e. the costs for which the benefit/cost-ratio is 1) are estimated at €285 per vehicle. If actual costs are lower, it is cost-effective to promote improved vehicle compatibility in all new vehicles in EU-25.

Figure 11 Benefit/cost-ratio depending on unit costs per vehicle



The robustness of the results (i.e. the estimated break-even unit cost) to the values used has been evaluated. The results of selected sensitivity analyses are shown in the table below.

Table 8-6 Results of sensitivity analyses - Improved vehicle compatibility

Sensitivity analysis	Break-even unit costs (€/vehicle)
1. Low effect on accident severity (see section 8.5)	140
2. High effect on accident severity (see section 8.5)	400
3. Low market penetration rate in 2025 (25%)	300
4. High market penetration rate in 2025 (75%)	280
5. Low average lifetime of vehicle (12 years)	255
6. High average lifetime of vehicle (16 years)	300

It can be seen that the estimated effectiveness of the technology has a large impact on the estimated break-even unit costs, whereas the market penetration rate for 2025 and the assumed lifetime of the vehicle is of minor importance.

9 Technology 1.4: Under-run protection

9.1 Definition of technology

Under-run protection systems can be described as follows:

"Under-run guardrails on the back of lorries and large trailers are designed to prevent cars and other vehicles from driving under the overhang of large vehicles. The objective of under-run guardrails is therefore to reduce the severity of injuries. The objective of side under-run protection is, first and foremost, to prevent pedestrians and road users riding two-wheeled vehicles from being run over, by getting caught in the open space between the wheel axles on large vehicles. Side under-run protection can also prevent smaller cars from driving under or between pairs of wheels on larger vehicles"[42].

Evidence shows that the vast majority of trucks have under-run protection on the back, but not on the sides or under-run guardrails. Hence the focus here is on assessing costs and benefits of making side-under-run protection and guardrails obligatory for HGV > 3.5 tons.

9.2 Accidents - Do-nothing scenario

The under-run guardrails and side under-run protection apply only to trucks and lorries.

The technology has an effect on two types of accidents:

- Vulnerable road user hit by a truck making a right turn
- Accidents in which cars hit the truck in the side.

TRL (2004) estimates - on the basis of CARE statistics - that approx. 9,000 pedestrians and 3,400 cyclists are killed per year in EU-25.

Likewise, TRL (2004) estimates that 75,000-175,000 pedestrians and 49,000-115,000 cyclists are severely injured per year in EU-25.

No data is available for slight injuries.

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[42] Elvik & Vaa (2004, page 734)

Data for the Netherlands for 1996 - presented in Jacobs Consultancy (2004) - indicates that HGV were involved in 18.5% of fatal accidents with bicycle and moped riders. The corresponding figure for severe injuries is 3.4%.

Furthermore, data from TNO for the Netherlands in 1996- also presented in Jacobs Consultancy - shows that some 36% of total accidents in collisions between bicycles/mopeds and goods vehicles are "blind spot accidents", defined as goods vehicles turning right and bicycles/mopeds going straight ahead. This figure is confirmed by Danish accident statistics[43].

If these figures are representative for the whole of EU-25, approx. 1.5% of all fatalities in EU-25 can be considered as cyclists/moped riders/pedestrians being killed by a HGV turning right. A similar figure is presented in TNO (1998) in a study on the situation in the Netherlands. For severe injuries the share appears to be slightly lower. Here a figure of 1.25% is used.

Due to a lack of the data the same figure is applied for slight injuries.

Accident data is not readily available for cars hitting trucks in the side for the whole of EU-25. However, data from Danmarks Statistik (2003) indicates that this accounts for approx. 1% of all fatalities, severe injuries and slight injuries. It is here assumed that this figure is representative for EU-25.

The aggregate figures used for the assessment of the benefits of installing side-under-run protection and guardrails on all new trucks are shown in the table below.

Table 9-1 Share of injuries in relevant accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-15	2.5%	2.5%	2.7%
NMS	2.5%	2.5%	2.7%

9.3 Scenario for implementation

None of the available studies provide exact numbers of the share of HGV equipped with side under-run protection/under-run guardrails.

In the main analysis it simply assumed that 10% of the truck fleet will have the side under-run protection/under-run guardrails installed in 2025, even if nothing extraordinary is done to promote under-run protection or the under-run guardrails.

43 Danmarks Statistik (2002)

Table 9-2 Market penetration - Under-run protection

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	0%	10%
Do-something	0%	100%

Sensitivity analyses are made for a market deployment rate of 0% (low) and 20% (high) in 2025 for the Do-nothing scenario. These analyses show that the assumed level of market penetration has only a minor effect on the benefit/cost-ratio.

The development of the size of the fleet of HGV is based on the data presented in 4.3.

9.4 Cost assessment

Elvik & Vaa (2004, page 735-736) report that unit costs are in the region of €1,250/truck for side under-run protection and under-run guardrails as an average for all trucks. As no other available study provides solid cost estimates, this figure is used here.

9.5 Safety impacts

Under-run-protection does not affect the risk of collision, but evidence shows that it has a rather large impact on the severity of accidents in case they occur.

A British study[44] has shown that under-run protection will mean that 29% of fatalities are prevented or reduced to severe injuries. This applies to accidents where both cars and trucks/lorries are involved. The study only analyses how many fatalities can be prevented. Here the same figure is assumed to be applicable for both severe and slight injuries.

Likewise, figures from the European Transport Safety Council (2005) indicate that 45% of pedestrian and cyclist fatalities could be saved. Again this figure is assumed to be applicable to both severe and slight injuries. It is here pragmatically assumed that the accidents shift one category down, as there is no data on this.

The figures used are reported in the two tables below. The figures reflect a weighted average for cars and vulnerable road users.

[44] Referred to in Elvik & Vaa (2004, page 735).

Table 9-3 Accident severity matrix - Under-run protection

Before	After Fatalities	Severe injuries	Slight injuries	Avoided
Fatalities changing to…		39% (29%-45%)	0%	0%
Severe injuries changing to…	0%		39% (29%-45%)	0%
Slight injuries changing to…	0%	0%		39% (29%-45%)

Note 1: From a statistical point of view the reduction in severity will not always shift down one severity class, i.e. the indication of 0% represents a simplification.

Note 2: Figures in brackets are the min/max values used in the sensitivity analyses.

9.6 Accidents - Do-something scenario

The effect on the number of fatalities, severe injuries and slight injuries is presented in the table below. As can be seen it is estimated that under-run protection on the sides or under-run guardrails on all new trucks can save 200-300 lives per year in EU-25.

Table 9-4 Study estimate of the effect of under-run protection in selected years

Category	2010	2020
Fatalities	-229	-314
Severe injuries	-2,017	-3,137
Slight injuries	-19,938	-30,710

9.7 Cost-benefit assessment

The costs and benefits of promoting under-run protection on the sides or under-run guardrails in trucks are shown in the table below.

As can be seen, benefits are estimated to outweigh costs by a factor 2.4.

Table 9-5 Main results of CBA - Under-run protection

Category	Net present value in 2005, million €
Accident costs	**13,584**
Fatalities	3,059
Severe injuries	4,069
Slight injuries	6,456
Total costs (Unit related)	**-5,653**
Total net present value	**7,930**
Benefit/cost-ratio	**2.4**

Note: Positive numbers reflect benefits, negative numbers reflect costs

The result - that under-run protection on the sides and under-run guardrails is a cost-effective measure for improving road safety - is confirmed by Elvik & Vaa (2004). Their calculations indicate a benefit/cost-ratio of close to 4.

Table 9-6 Results of sensitivity analyses - Under-run protection

Sensitivity analysis	BCR
1. Low unit costs (€750)	4.0
2. High unit costs (€1750)	1.7
3. Low effect on collision probability (se section 9.5)	1.8
4. High effect on collision probability (see section 9.5)	2.8
5. Low market penetration rate in 2025 (0%)	2.5
6. High market penetration rate in 2025 (20%)	2.3
7. Low average lifetime of vehicle (12 years)	2.2
8. High average lifetime of vehicle (16 years)	2.6

For all the values used in the sensitivity analyses, benefits exceed costs. However, the estimated benefit/cost-ratio is very sensitive to the unit costs and the safety effect. The results are robust regarding assumptions about the market penetration rate in 2025 for the Do-nothing scenario and the assumed lifetime of the vehicle.

10 Technology 1.5: eCall

10.1 Definition of technology

eCall can be defined as follows:

"The emergency-call gives precise coordinates of the location of an accident to the emergency services which are responsible for the help. The service is a multistakeholder function of public organisations, telecom companies and service providers and car manufacturers" [45].

10.2 Accidents - Do-nothing scenario

All accidents in EU-25 are relevant in relation to eCall[46].

10.3 Scenario for implementation

eCall is a very complex system as it involves all the stakeholders of the total rescue chain. Therefore it is difficult to assess a likely scenario for implementation (both for the Do-nothing scenario and the Do-something scenario) and the costs of implementing the system.

The assessment presented here is based on the assumption that 0% of the vehicles have the necessary technological equipment for the eCall system installed in 2006 (see table below). This is in line with the implementation scenario outlined in eSafety Forum Working Group (2005).

Furthermore, it is here assumed that the market penetration rate of eCall will remain at 0% unless something extraordinary is done to promote eCall. This is not in line with the estimated increase in the "business-as-usual" scenario of the eSafety Forum Working Group (2005), where market penetration is estimated at 20%-50% in 2020.

The main reason for assuming a 0% market penetration in 2020 is that the focus here is on costs and benefits of implementing a common European system, and because it is difficult to cover the issue of interoperability between existing sys-

[45] VDI/VDE/IT, IFV Köln (2005, page 105)

[46] See for example VDI/VDE/IT, IFV Köln (2005, page 104)

tems (private alternatives to eCall) in the cost-benefit assessment. The sensitively analyses shows that the results of the assessment is robust to this assumption.

Table 10-1 Market penetration - eCall

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	0%	0%
Do-something	0%	100%

Sensitivity analyses are made for a market deployment rate of 30% (high) in 2025 for the Do-nothing scenario.

It is outside the scope of this study to assess the practical and organisational issues relevant to the implementation of eCall. A discussion of these issues is presented in eSafety Forum Working Group (2005).

10.4 Cost assessment

It is, as mentioned, a complex task to estimate the cost of rolling out the eCall system and only rough calculations on the overall costs exist. The main sources of information for this assessment are VDI/VDE/IT, IFV Köln (2005) and E-MERGE (2004). It should be kept in mind that the cost estimates provided below are highly uncertain and unfortunately also incomplete.

E-MERGE (2004) identified the most important cost items associated with the implementation of eCall as being:

- Individual driver: Buying and installing the IVS
- PSAP, EA and service providers: Adjusting the call centres
- Vehicle manufacturers, insurance companies and service providers: Adjusting back-offices (not relevant for minimum eCall system)
- Training of staff.

In E-MERGE (2004) unit cost figures of €80-€600 are mentioned, depending on whether they refer to the cost price for the car makers or the end-user price. The cost-benefit assessment is here made for both a unit of €500 (scenario 1) and unit costs of €90 (scenario 2). In comparison, the calculations presented in VDI/VDE/IT, IFV Köln (2005) are based on unit costs of €100-€150.

The adjustment of call centres is estimated to cost €30,000-50,000 per centre. The number of actual PSAP in EU-25 is not given, but VDI/VDE/IT, IFV Köln (2005) provides a rough estimate on the basis of the empirical relationship between the number of PSAP and inhabitants. It is estimated that 1,500 PSAP is required in EU-25.

The training of staff is estimated at €300-1500 per service employee per year, when training is integrated with existing training programmes. The average number of people working at a PSAP is 60, according to VDI/VDE/IT, IFV Köln (2005).

The table below shows the general cost estimates used here, together with the range of cost estimates used for the sensitivity analysis.

Table 10-2 Cost estimates - eCall

Cost category	Item	Best estimate	Minimum	Maximum
Individual driver: Buying and installing the IVS	Price per vehicle in €	500 (scenario 1) 90 (scenario 2)		
Adjusting the call centres	Cost per call centre in €	40,000	30,000	50,000
	Number of call centres	1,500	1,000	2,000
Training of staff (only PSAP)	Training costs (per employee per year) in €	900	300	1500
	Number of employee per PSAP	60	-	-

The costs presented in the table above do not, as mentioned, cover the total costs of rolling out the eCall system. Other costs which may be significant include investments in police/fire/ambulance centres and training of their staff and cost of mobile operators for adjustment of network. It has however not been possible to quantify these costs.

The estimate on the overall costs of eCall in EU-25 is presented in the table below for both scenario 1 (unit costs=€500) and scenario 2 (unit costs=€90).

Table 10-3 Overall costs - eCall (net present value in 2005, million €)

Cost category	Scenario 1 (unit costs=€500)	Scenario 2 (unit costs=€90)
Individual driver: Buying and installing the IVS	106,271	19,129
Adjusting the call centres	54	54
Training of staff (only PSAP)	932	932
Total	107,258	20,115

10.5 Safety impacts

The eCall system leads to a higher efficiency of the rescue chain in the form of lowering the rescue time. Hence the eCall system does not affect the vehicle collision probability[47], but instead affects the severity of the accident by reducing rescue time.

When medical care to critically injured people is available faster after the accidents, the death rate can be lowered. Evidence shows that e.g. one hour after the accident, the death rate of people with heart or respiratory failure or massive bleeding is close to 100% (known as the Golden Hour Principle of accident medicine). Furthermore evidence shows that severe accidents can be reduced to slight accidents when rescue time is lowered.

A wide span of figures is reported in the literature on the impact of eCall on the severity of accidents. The E-MERGE project estimates, on the basis of surveys in different western European countries, that 2-7% of road fatalities can be reduced to severe injuries and 10%-15% of the severe injuries can be changed to slight injuries[48]. VDI/VDE/IT, IFV Köln (2005) report figures of 5%-15% for changes in road fatalities to severe injuries and 10%-15% for changes of severe injuries to slight injuries[49].

In Sweden, the full implementation of eCall has been estimated to reduce the number of road accident fatalities by 2-4% and the number of severely injured by 3-5% (Lind et al (2003), reported in eSafety Forum Working Group (2005)).

For Finland, Virtanen et al (2006, page 8) estimate that "… the eCall system would very likely have prevented 4.7% of the fatalities of participants inside motor vehicles in 2001-2003…. In addition to this there were 5% of the fatalities where the eCall could possibly have helped". About the transferability of these results to Europe Virtanen et al (2006, page 13) conclude: "Compared to almost all the rest of Europe Finland has a lot of lightly trafficked roads and severe winter conditions and thus the self-alarming eCall system could be more benficial here than in the rest of Europe".

As can be seen, these figures are much lower than the figures presented in E-MERGE (2004) and VDI/VDE/IT, IFV Köln (2005).

The figures used here are reported in the table below.

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[47] VDI/VDE/IT, IFV Köln (2005, page 105)

[48] E-MERGE (2004)

[49] The figures used in VDI/VDE/IT, IFV Köln (2005) are based on figures from E-MERGE (2004) and the eSafety Driving Group.

Table 10-4 Accident severity matrix - eCall

Before	After: Fatalities	Severe injuries	Slight injuries	Avoided
Fatalities changing to…		4% (2-15%)	0%	0%
Severe injuries changing to…	0%		7% (3-15%)	0%
Slight injuries changing to…	0%	0%		0%

Note 1: From a statistical point of view the reduction in severity will not always shift down one severity class, i.e. the indication of 0% represents a simplification.
Note 2: Figures in brackets are the min/max values used in the sensitivity analyses.

10.6 Accidents - Do-something Scenario

The effects on the number of fatalities and injuries are summarised in the table below.

eCall is estimated to reduce the severity of accidents due to a more efficient rescue chain. It is here estimated that 897 lives can be saved in 2010. The corresponding data for severe/slight injuries are provided in the table below together with data for 2020. It can be seen that the number of lives saved increases to 1,392 in 2020 when all vehicles have installed the required equipment.

Table 10-5 Study estimate of the effect of eCall in selected years

Category	2010	2020
Fatalities	-897	-1,392
Severe injuries	-15,708	-27,485
Slight injuries	16,605	28,877

10.7 Cost-benefit assessment

The results of the cost-benefit assessment of eCall are presented below for both scenario 1 (unit costs=€500) and scenario 2 (unit costs=€90).

Table 10-6 Main results of CBA - eCall

Category	**Net present value in 2005, million €**	
	Scenario 1 (unit costs=€500)	Scenario 2 (unit costs=€90)
Accident costs	**41,127**	**41,127**
Fatalities	12,858	12,858
Severe injuries	34,059	34,059
Slight injuries	-5,790	-5,790
Total costs	**-107,258**	**-20,115**
Unit related costs	-106,271	-19,129
Investment costs PSAP	-54	-54
Training of staff	-932	-932
Total net present value	**-66,169**	**20,974**
Benefit/cost-ratio	**0.4**	**2.0**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

It seems clear that the estimated costs of eCall greatly exceed the incurred benefits, if the correct figure for the unit costs is €500. However if the costs per vehicle is only €90, benefits are estimated to exceed costs by a factor 2.

It should, however, be kept in mind that the cost figures presented do not include the total costs of rolling out the eCall-system.

The estimated benefit/cost-ratio is very much in line with the results of Virtanen et al (2006). Virtanen et al (2006) estimates the benefit/cost-ratio to be between 0.5 and 2.3 for Finland.

The figures presented above, however, vary markedly from the exemplary cost-benefit calculations for eCall presented in VDI/VDE/IT, IFV Köln (2005), in which the annual benefits are estimated at €5.8 billion for the "pessimistic view" and €25 billion for the "optimistic view". Here annual benefits are estimated at approx. €4.4 billion when all vehicles have the technology installed.

The corresponding annual cost estimates of eCall are €4.5 billion and €3.0 billion for the pessimistic view and the optimistic view respectively. The benefit-ratio is therefore estimated to be in the range of 1.3 and 8.5.

Here costs are estimated to be almost the double of the cost estimate for the pessimistic view in VDI/VDE/IT, IFV Köln (2005) where unit costs are assumed to be €500. For a unit cost of €90, the total annual costs are here estimated to be in the region of €2 billion.

E-MERGE (2004) estimates that the benefits of eCall will amount to €3-5 billion on a yearly basis, which is in line with the figures presented here, whereas the necessary investments are approx. €20 billion.

In general it can be concluded - also taking into account the sensitivity analyses presented in the table below - that it is highly uncertain whether eCall is a cost-effective measure for improving road safety.

Table 10-7 Results of sensitivity analyses - eCall

Sensitivity analysis	BCR (Scenario 1, unit costs=€500)	BCR (Scenario 2, unit costs=€90)
1. Low effect on accident severity	0.2	0.9
2. High effect on accident severity	1.0	5.3
3. High market penetration rate in 2025 (30%)	0.3	1.8
4. Low average lifetime of vehicle (12 years)	0.4	1.9
5. High average lifetime of vehicle (16 years)	0.4	2.2

11 Technology 1.7: Collision warning and similar systems

11.1 Definition of technology

Collision warning systems, etc. can be described as follows:

"In a collision or obstacle warning system predictive sensors like infrared, radar, laser, ultrasonic and cameras calculate the likelihood of a crash. An appropriate warning system can inform the driver of dangerous situations in advance or activate a potential pre-crash /crash avoidance system.

A pre-crash system prepares the car for an unavoidable crash by activating the passive safety systems (including e.g. smart restraint systems, head rests, seat position, systems for protecting vulnerable road users, etc.).

A crash avoidance system takes over when there is not enough time left for the driver to avoid the accident. This system independently initiates appropriate action. A relatively simpler version of crash avoidance is the emergency braking system (EBS), which brakes the car with maximum deceleration to reduce the accident severity in cases where a crash can not be avoided[50]."

The assessment presented in this study is based on a collision warning system including some pre-crash facilities, but without emergency braking/crash avoidance functions.

11.2 Accidents - Do-nothing scenario

Depending on the exact composition of the system collision warning, emergency braking and crash avoidance systems are targeted at reducing the risk of rear end and head on collisions, side collisions, merging and intersection collisions, vehicle-pedestrian collisions, collisions with obstacles and left roadway accidents. Pre-crash systems are targeted at the same types of accidents[51].

[50] VDI/VDE/IT, IFV Köln (2005, page 37-41)

[51] VDI/VDE/IT, IFV Köln (2005, page 26)

The different types of collision warning, crash avoidance systems etc are thus relevant for approx. 70-90% of all accidents in Germany[52]. In 11 EU-15 countries the corresponding values are approx. 75-95% of all fatalities[53].

First generation collision warning systems are estimated to influence 50-70% of total accidents according to Bosch (2005b) and SAFETYNET (2005).

Based on this it is estimated in this study that first generation collision warning systems can influence accidents and injuries as presented in Table 11-1.

Table 11-1 Share of injuries in relevant accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-15	60%	60%	60%
NMS	60%	60%	60%

As mentioned in chapter 7, Bosch (2005c) asserts that in more than 50% of all accidents, drivers do not brake at all, primarily because of inattention. In more than 45% of accidents drivers make a partial braking, mainly due to inexperience. Only in 1% of accidents is a full breaking performed.

Contrary to brake assist systems, collision warning and other more advanced systems are also able to influence those accidents where the driver has not activated the brake yet.

11.3 Scenario for implementation

In VDI/VDE/IT, IFV Köln (2005) it is stated that collision warning systems are likely to be introduced to the market in 2007-2008. Emergency braking systems are expected in 2009, while the more advanced crash avoidance systems are not expected until after 2015. In all cases the system is primarily seen as an optional safety function. The more complex systems may become mandatory later on.

Pre-crash systems are expected to be introduced as soon as in 2006 and are expected to become standard vehicle equipment[54].

For example, Bosch is working on a system called CAPS - Combined Active and Passive Safety, which includes all the mentioned elements[55].

Currently only limited solutions - supplementing adaptive cruise control systems - are available, using information obtained from radar sensors to give vis-

[52] Bosch (2005b)
[53] SAFETYNET (2005, page 44)
[54] VDI/VDE/IT, IFV Köln (2005, 37-41)
[55] Bosch (2005c)

ual and acoustic warnings. Estimated market penetration in new cars in the "business as usual" scenario is given as very low in 2005 (0-5%), low in 2010 (5-20%) and medium in 2020 (20-50%). In an EU support scenario the market penetration is expected to increase to medium in 2010 and high in 2020 (50-80%)[56].

ERTICO (2005) states that forward collision systems have been used in heavy trucks for more than 10 years in the USA and that collision mitigation braking was introduced in Japan in 2003[57].

The expected market penetration used in this study can be seen in Table 11-2.

Table 11-2 Market penetration - Collision warning systems

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	0%	20%
Do-something	0%	100%

Sensitivity analyses are made for a market deployment rate of 10% (low) and 40% (high) in 2025 for the Do-nothing scenario.

11.4 Cost assessment

No solid costs estimates are available for collision warning systems. Hence the break-even unit costs have been estimated.

In VDI/VDE/IT, IFV Köln (2005) it is however mentioned that investment and operating costs are medium/high and low/medium for collision warning systems, high and low for emergency braking systems and high and high for crash avoidance systems respectively. For pre-crash systems investment costs are given as low/medium and operating costs as low.

It is similarly stated in PRISM (unknown) that e.g. reversible electric seat belts that fasten during anti-lock braking and brake assistance conditions are relatively simple to implement.

11.5 Safety impacts

The potential of a collision warning system (including some pre-crash, but without emergency braking/crash avoidance functions) has been assessed for Germany by the producer Bosch. The system is expected to save 510 fatalities

[56] eSafety Forum Working Group (2005, page 9-14 & 18)
[57] ERTICO (2005)

through collision avoidance and 330 fatalities through collision mitigation. The 840 saved fatalities correspond to 12% of the total fatalities in 2002[58].

Collision avoidance is furthermore expected to save a total of 9,000 severe and 53,000 slight injuries, corresponding to 10% and 14% of total severe and slight injuries in Germany respectively. In the same way collision mitigation is expected to save 6,000 severe and 30,000 slight injuries, corresponding to 7% and 8% of total injuries respectively[59].

A somewhat lower reductive effect of 4-6% on total fatal accidents is stated in the eSafety Forum Working Group (2005).

Another producer of collision warning systems for trucks (Eaton Vorad) mentions much higher safety effects, from a 51% reduction in serious accidents to 73% fewer accidents. Specifically one fleet is stated to cut rear end and lane change accidents to nil, while another is said to reduce accidents involving fixed objects (left roadway) to 81%. A 92% reduction of the accident rate is also mentioned[60].

Given that collision warning systems are estimated to influence 60% of total accidents, the unit effect is estimated to be approximately a factor 1.7 above the potential for all accidents from Bosch.

Table 11-3 Reduction in collision probability - Collision warning systems

Fatalities	12% (8%-16%)
Severe injuries	20% (10%-30%)
Slight injuries	20% (10%-30%)

In collision mitigating, accident consequences according to Bosch are expected to shift down a severity class.

58 Bosch (2005c)
59 Bosch (2005b)
60 Roadranger (2005)

Table 11-4 Accident severity matrix -Collision warning systems

Before	After Fatalities	Severe injuries	Slight injuries	Avoided
Fatalities changing to…		8% (4%-12%)	0%	0%
Severe injuries changing to…	0%		12% (8%-16%)	0%
Slight injuries changing to…	0%	0%		12% (8%-16%)

Note 1: From a statistical point of view the reduction in severity will not always shift down one severity class, i.e. the indication of 0% represents a simplification.
Note 2: Figures in brackets are the min/max values used in the sensitivity analyses.

Emergency braking and crash avoidance systems are expected to have a greater effect than the above for a less advanced collision warning system. Thus a study mentions effects of a 45-80% reduction in total fatalities due to a more advanced action-taking collision mitigation system[61].

11.6 Accidents - Do-something scenario

The effects of collision warning systems on the number of fatalities and injuries are summarised in Table 11-5.

Collision warning systems are estimated to reduce the risk and severity of accidents by warning drivers of potential collisions. It is in this study estimated that EU implementation of collision warning systems can save 2,222 lives in 2010 and 2,930 lives in 2020 when all vehicles have installed the required equipment. Corresponding figures for reductions in severe and slight injuries appear in the table below.

Table 11-5 Study estimate of the effect of collision warning systems in selected years

Category	2010	2020
Fatalities	-2,222	-2,930
Severe injuries	-36,298	-53,333
Slight injuries	-353,780	-520,416

61 Danmarks Transportforskning (2002, page 29-30)

11.7 Cost-benefit assessment

The net present value of the net benefits of promoting the use of collision warning systems is presented in the table below. The benefit/cost-ratio can however not be estimated due to a lack of solid cost estimates.

Table 11-6 Main results of CBA - Collision warning systems

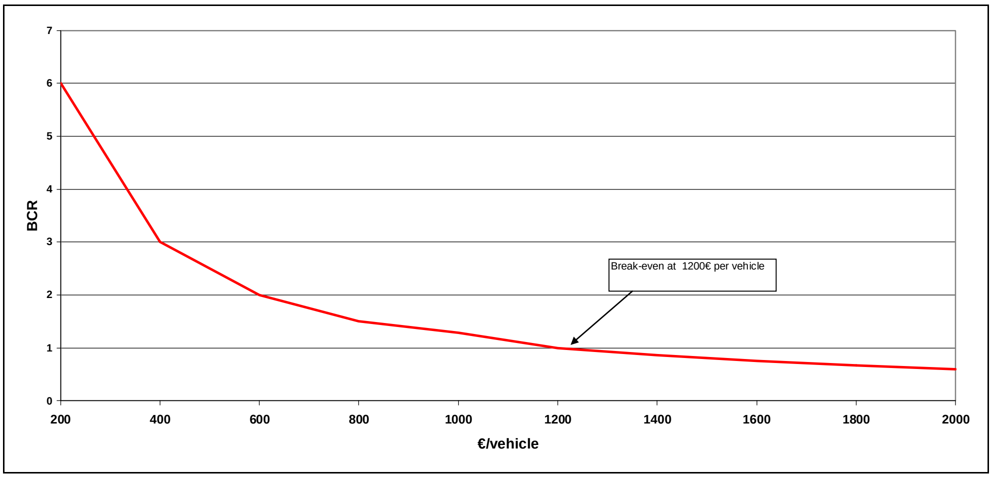
Category	Net present value, million €
Accident costs	**211,287**
Fatalities	29,014
Severe injuries	70,799
Slight injuries	111,474
Total costs	**?**
Total net present value	**?**
Benefit/cost-ratio	**?**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

As no solid cost estimates are available, the benefit/cost-ratio has been estimated for a range of unit costs. The result is presented in the figure below. It can for example be seen that the benefit/cost-ratio would be 6 if the cost of implementing collision warning systems was €200 per vehicle.

The break-even costs (i.e. the cost for which the BCR is 1) is estimated at €1,200 per vehicle. If actual costs are lower it is cost-effective to install collision warning systems in all new vehicles in EU-25.

Figure 12 Benefit/cost-ratio depending on unit costs per vehicle - Collision warning systems



The robustness of the results (i.e. the estimated break-even unit cost) to the values used has been evaluated. The results of selected sensitivity analyses are shown in the table below.

Table 11-7 Results of sensitivity analyses - Collision warning systems

Sensitivity analysis	Break-even unit costs (€/vehicle)
1. Low effect on collision probability/accident severity (see section 11.5)	690
2. High effect on collision probability/accident severity (see section 11.5)	1,690
3. Low market penetration rate in 2025 (10%)	1,240
4. High market penetration rate in 2025 (40%)	1,140
5. Low average lifetime of vehicle (12 years)	1,090
6. High average lifetime of vehicle (16 years)	1,290

It can be seen that the estimated effectiveness of the technology has a large impact on the estimated break-even unit costs, whereas the market penetration rate for 2025 and the assumed lifetime of the vehicle is of minor importance.

12 Technology 1.8: Adaptive cruise control (ACC)

12.1 Definition of technology

Adaptive cruise control (ACC) can be defined as follows:

"Adaptive cruise control is a system which will enable the vehicle to maintain a driver-defined distance from the preceding vehicle while driving within a maximum speed limit - again set by the driver. The system is designed primarily for use on motorways and rural roads as it only functions at speeds between 30 and 200 km/h. If there is a rapid reduction in the vehicle's speed, the system will warn the driver and switch off for driver control[62]."

12.2 Accidents - Do-nothing scenario

Adaptive cruise control is targeted at reducing the risk of rear end collisions[63].

It is estimated that 15% of accidents in Germany involve insufficient distance between vehicles according to eSafety Forum Working Group (2002, page 24). Bosch (2005b) mentions that rear end collisions make up 21% of accidents in Germany. In Denmark the corresponding share is 12% of accidents and 13% of fatalities[64].

In a study of ten other countries in EU-15 it is stated that rear end collisions account for 13% of injuries and 4% of fatalities[65]. The percentage is assumed to be the same on average for the remaining countries in EU-15 and the new member states[66].

Newer data in SAFETYNET (2005, page 44) shows that approximately 8% of fatalities registered in 11 of the EU-15 countries are in connection with rear end collisions.

[62] VDI/VDE/IT, IFV Köln (2005, page 112-118)
[63] VDI/VDE/IT, IFV Köln (2005, page 112-118)
[64] Danmarks Statistik (2003, page 17-18)
[65] SWOV (2003, page 6-9)
[66] VDI/VDE/IT, IFV Köln (2005)

Based on this it is estimated in this study that adaptive cruise control can influence accidents and injuries as presented in Table 12-1.

Table 12-1 Share of injuries in relevant accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-15	13%	13%	6%
NMS	13%	13%	4%

12.3 Scenario for implementation

ERTICO (2005) states that adaptive cruise control was available in 1995 in Japan, in Europe in 1998 and in USA in 2000, while VDI/VDE/IT, IFV Köln (2005) states that adaptive cruise control was introduced in 2000 as an optional comfort function. It is in the latter study further estimated that the market diffusion rate in 2010 will be 3% and 8% in 2020.

It is assessed in this study that 1% of the vehicles will have adaptive cruise control installed in 2006. Based on the prediction in VDI/VDE/IT, IFV Köln (2005) it is furthermore assumed that the penetration rate will increase even if nothing extraordinary is done to promote ACC systems. In 2025 it is thus estimated that 10% of the vehicles will have ACC in the "business as usual" scenario, as presented in Table 12-2.

Table 12-2 Market penetration - Adaptive cruise control

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	1%	10%
Do-something	1%	100%

Sensitivity analyses are made for a market deployment rate of 25% (low) and 75% (high) in 2025 for the Do-nothing scenario.

The statistical risk of an accident is correlated with vehicle-kilometres. From an economic point of view, implementing ACC is therefore of greatest benefit to those drivers with the highest vehicle-kilometres per year. It is assumed that an 8% market diffusion in 2020 will cover 15% of vehicle-kilometres. A 10% market diffusion will correspondingly affect 20% of vehicle-kilometres[67]. A similar relationship is, as described in section 4.4, used in this study.

[67] VDI/VDE/IT, IFV Köln (2005, page 112-118)

12.4 Cost assessment

According to VDI/VDE/IT, IFV Köln (2005), per unit costs have been forecast at €750 in 2010 and €400 in 2020.

An American reference gives a market price of $800 for ACC[68], while ERTICO (2005) mentions unit prices of €600-3,500.

Based on these estimates, a unit cost of €750 is used in the main analyses. To analyse the robustness of the results to the unit costs sensitivity analyses are made for a unit cost of $400 (low) and €3,500 (high).

12.5 Safety impacts

The accident prevention potential of adaptive cruise control is, according to VDI/VDE/IT, IFV Köln (2005), 25% for rear end collisions. Furthermore the lower vehicle speed and crash impact also influence the severity of those accidents which cannot be avoided. It is thus assumed that 20% of accidents can be shifted down a severity class - that is from fatality to severe injury and from severe to slight injury. No change is expected from slight to no injury.

TØI gives much higher effects in studies of ACC systems, namely an approximate 50% reduction in rear end collisions[69]. In another connection TØI has calculated that ACC can reduce total fatalities by 1% in Norway and 1% in Sweden[70]. This would correspond to a maximum of 25% of fatalities in registered rear end collisions in Sweden[71].

The effects used in this study are presented in Table 12-3 and Table 12-4.

Table 12-3 Reduction in collision probability - Adaptive cruise control

Fatalities	25% (15%-50%)
Severe injuries	25% (15%-50%)
Slight injuries	25% (15%-50%)

Note: Figures in brackets are the figures used as min/max-values in the sensitivity analyses

68 Auto Briefing (2005a, page 7)
69 Elvik & Vaa (2004, page 710)
70 Elvik (2005)
71 SAFETYNET (2005, page 44)

Table 12-4 Accident severity matrix - Adaptive cruise control

Before	After Fatalities	Severe injuries	Slight injuries	Avoided
Fatalities changing to…		20%	0%	0%
Severe injuries changing to…	0%		20%	0%
Slight injuries changing to…	0%	0%		0%

Note 1: From a statistical point of view the reduction in severity will not always shift down one severity class, i.e. the indication of 0% represents a simplification.
Note 2: Figures in brackets are the min/max values used in the sensitivity analyses.

12.6 Accidents - Do-something Scenario

The effects of adaptive cruise control systems on the number of fatalities and injuries are summarised in Table 12-5.

It is estimated in this study that adaptive cruise control systems can reduce the potential and severity of rear end collisions. It is thus estimated that EU implementation of adaptive cruise control systems can save 485 lives in 2010 and 679 lives in 2020 when all vehicles have installed the required equipment. Corresponding figures for reductions in severe and slight injuries appear in the table below.

Table 12-5 Study estimate of the effect of adaptive cruise control in selected years

Category	2010	2020
Fatalities	-485	-679
Severe injuries	-11,750	-18,376
Slight injuries	-64,325	-106,025

12.7 Cost-benefit assessment

The results of the cost-benefit analysis for adaptive cruise control systems are presented in Table 12-6.

As can be seen, the costs of installing adaptive cruise control more than outweigh the benefits.

It should be noted that the costs of vehicle technologies tend to decrease over time. Hence adaptive cruise control could prove to be a cost-effective measure in the future.

Table 12-6 Main results of CBA - Adaptive cruise control

Category	Net present value in 2005, million €
Accident costs	**52,007**
Fatalities	6,537
Severe injuries	23,760
Slight injuries	21,709
Total costs (unit related)	**-145,491**
Total net present value	**-93,484**
Benefit/cost-ratio	**0.4**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

In comparison, VDI/VDE/IT, IFV Köln (2005) presents results on exemplary cost-benefit calculations for adaptive cruise control. Annual benefits and costs for EU-25 are estimated at €490 and 540 million in 2010 and €990 and 840 billion in 2020 respectively. This results in benefit/cost-ratios of 0.9 and 1.2.

The main reason why the benefit/cost-ratio is lower in this study compared to the VDI/VDE/IT, IFV Köln (2005) seems to be that the effects of implementing ACC are estimated to be relatively lower in this study, due to higher uniform unit prices, expected market penetration in the "business-as-usual scenario" and continuous change in crash and casualty rates due to improved vehicles and roads (see chapter 4).

TØI has calculated a benefit/cost-ratio of 0.5-0.6 for implementation of adaptive cruise control in Norway and Sweden[72]. This ratio is more similar to the calculations in this study.

The robustness of the results to the values used is therefore evaluated. The results of selected sensitivity analyses are shown in the table below.

For all the values used in the sensitivity analyses, costs exceed benefits. However, the estimated benefit/cost-ratio is very sensitive to the unit costs and the safety effect. The results are robust regarding assumptions about the market penetration rate in 2025 for the Do-nothing scenario and the assumed lifetime of the vehicle.

[72] Elvik (2005)

Table 12-7 Results of sensitivity analyses - Adaptive cruise control

Sensitivity analysis	BCR
1. Low unit costs (€400)	0.7
2. High unit costs (€3,500)	0.2
3. Low effect on collision probability (see section 12.5)	0.2
4. High effect on collision probability (see section 12.5)	0.7
5. Low market penetration rate in 2025 (5%)	0.4
6. High market penetration rate in 2025 (20%)	0.4
7. Low average lifetime of vehicle (12 years)	0.3
8. High average lifetime of vehicle (16 years)	0.3

13 Technology 2.1: Daytime running lights

13.1 Definition of technology

Vehicle visibility is a factor which has a large effect on accidents, as many accidents occur because road users do not notice each other in time.

The use of daytime running lights for cars in all light conditions is therefore believed to reduce the number of multi-party accidents by improving visibility.

The costs and benefits of "requiring new cars to have automatic DRLs (dedicated DRLs)" are analysed here. Cars that do not have dedicated DRLs will not be required to turn on headlights, i.e. what is analysed is a simple technical measure[73].

13.2 Accidents - Do-nothing scenario

Data on the total number of accidents in EU-25 were presented in section 4.1. The use of DRL will however not have an impact on all types of accidents.

According to several studies - including Elvik & Vaa (2004), TNO (unknown) and Wesemann et al (2003) - the use of DRL influences multi-party daytime accidents only.

In TNO (unknown) it is estimated that multi-party daytime accidents make up 40% of all fatal or injury accidents in the European Union. In Elvik & Vaa (2004) it is estimated that for Norway, 50% of injury accidents reported to the police are multi-party daytime accidents. In the SWOW (2003) study (a revised version), a figure of 40% was used, with a remark that it is a conservative estimation. ETSC also refer to a figure of 40% as an average for the EU. As the focus here is on EU-25, a figure of 40% is applied in this study.

Furthermore, it is necessary to correct for the fact that DRL is currently compulsory in several countries; Denmark, Finland, Italy, Sweden, Czech Republic, Hungary, Poland and Lithuania[74].

[73] Equivalent with one of the scenarios analysed in TNO (unknown)

[74] Elvik & Vaa (2004, page 638) and TNO (unknown a).

The table below summarises the accident statistics relevant for the evaluation of DRL.

Table 13-1 Share of injuries in relevant accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-25	40%	40%	40%

13.3 Scenario for implementation

Some vehicles use DRL in the countries although they are not compulsory. The current use is - in line with the assumption made in TNO (unknown) and the European Transport Safety Council (2003) - assumed to be 10% in the countries under consideration. It is assumed that this share will remain constant over the forecast period if nothing extraordinary is done to promote the use of DRL.

A sensitivity analysis is made for a market deployment rate of 25% (high) in 2025 for the Do-nothing scenario.

It is assumed that new cars sold in 2007 and after this are required to have dedicated DRL that are turned on automatically. Cars that do not have dedicated DRL will not be required to turn on headlights.

This implies that the use DRL will increase from the current level of 10% to 100% in line with the renewal of the vehicle fleet.

The countries where DRL is already compulsory account for 39% of the vehicle fleet. These are of course not included in the analysis. Hence the total relevant fleet of vehicles amounts to 167.4 million in 2020.

13.4 Cost assessment

The costs of implementing the scenario outlined above consist of:

- The cost of installing dedicated DRLs
- More frequent replacement of light bulbs
- Increased fuel consumption
- Increased air pollution

Cost of installation

The installation of dedicated DRLs is - in line with TNO (unknown) - estimated to cost €25 per car, which is a one-time cost.

The net present value of the installation costs are estimated at €3,395 million.

More frequent replacement of light bulbs
According to Wesemann et al (2003) the effect of DRL on bulb lifespan will result in €6 per car per year. ETSC (2003) refer to a price of €5 per vehicle. Furthermore, Elvik and Vaa (2004) report cost figures in the region of €2-12 per car per year in current prices for increased bulb usage.

A figure of €6 per car per year is applied here.

The net present value of more frequent replacement of light bulbs is €6,435 million.

Increased fuel consumption
Finally, TNO (unknown) also estimated that DRL could be expected to lead to increased fuel consumption and thereby an environmental impact of 1.6% for small cars using petrol and 0.7% for heavy vehicles using diesel. For small and large vehicles taken together, fuel consumption in TNO is estimated to increase by 1.35%.

In line with this, Elvik & Vaa (2004) report that Glad, Assum and Bjørgum (1985) estimate that the use of DRL leads to an increase in fuel consumption of approx. 1-2%.

Given that dedicated DRL consume 38% less fuel (using 2*21W) than standard low beam headlights (using 2*55 W), a figure of (1-38%)*1.35%=0.83% is applied here.

Given an assumption that vehicles drive an average of12,000 km per year (which is in line with figures presented in the TNO study), an average vehicle drives 10 km/litre and a litre of fuel on average costs €0.4 [75](excluding taxes and duties). The net present value of costs of extra fuel consumption is therefore estimated at €3,827 million.

Increased air pollution
Several estimates on marginal external costs per km driving are provided in the TNO-study. The average seems to be approx. €0.04/km. On the basis of the assumption that fuel consumption increases by 0.83%, this translates to a figure of €0.000332/km per kilometre driven with DRL. The net present value of the extra external costs is on this basis estimated at €4,273 million.

Aggregate costs
The aggregated costs of introducing DRL in the countries where DRL is currently not compulsory are provided in the table below. As can be seen the net present value of total costs is estimated at €15.9 billion.

[75] European Road Fund, section 8 of: [http://www.erf.be/section/statistics?PHPSESSID=98bd8c572120713a10cf2ce8b0d4653e]

Table 13-2 Aggregate cost estimate - Daytime running lights

Category	Net present value in 2005, million €
Installation costs	3,395
More frequent replacement of light bulbs	6,435
Increased fuel consumption	3,827
Increased external costs	4,273
Total	**15,880**

13.5 Safety impacts

There is evidence that the effects of DRL vary according to accident severity. DRL is found to have the largest effect on the most severe injuries.

The analysis provided in TNO (unknown) shows that the use of DRL reduces the number of multi-party daytime accidents for cars by 5-15%[76].

In the cost-benefit analysis of TNO (unknown, page 5) it is assumed that DRL reduce fatal multi-party daytime accidents by 15%, serious injury multi-party daytime accidents by 10% and slight injury multi-party daytime accidents by 5%. No effect on property-damage only accidents was assumed in the CBA of TNO.

Elvik & Vaa (2004, page 638) report comparable figures on the effectiveness of DRL, while Koornstra et al (1997) found a reduction of 12.4% for multi-party daytime accidents.

The assumed effect of DRL on a change in collision probability is provided in the table below.

Table 13-3 Reduction in collision probability - Daytime running lights

Fatalities	-15% (10%-20%)
Severe injuries	-10% (5%-15%)
Slight injuries	-5% (0%-10%)

Note: For multi-party daytime accidents. Figures in brackets refer to min/max-values used in the sensitivity analyses
Source: Based on TNO (unknown b, page 5), Elvik and Vaa (2004, page 638)

Theoretically DRL could have an effect on the severity of accidents if accidents occur due a possible lower speed at collision. However, this effect is not taken

[76] Based on a systematic review of 41 studies of which 25 have evaluated the effect for cars (see TNO (unknown)).

into account here as none of the available studies provide estimates on this effect.

Considering the effectiveness of different types of DRLs, TNO (unknown, page 69) conclude: "When considering all available evidence, it is therefore concluded that there is no strong evidence to support an assumption that dedicated DRLs are more effective than ordinary low beam headlights. There is on the other hand no evidence of the contrary. Apparently, both low beam headlights and dedicated DRLs are fully satisfactory as daytime running lights".

Based on this, no distinction is made here with respect to the effectiveness of the different types of DRLs.

Furthermore this study is based on the following assumptions which were also made in TNO (unknown):

– The effect of DRL is constant over time
– There are no seasonal variations in the effect of DRL

Furthermore, TNO provides considerable evidence that DRL is unlikely to have any adverse effects on accidents involving pedestrians, cyclists, motorcyclists and rear end collisions which has been suspected elsewhere. In Elvik and Vaa (2004) it is stated that "The number of accidents where pedestrians and cyclists are involved is reduced. The same applies to the number of head-on/right angle collisions between cars. However, the number of rear end collisions appears to increase". Given the uncertainty on these effects they have not been included here, which is in line with what is done in Elvik & Vaa (2004) and TNO (unknown).

13.6 Accidents - Do-something scenario

The effects on the number of fatalities and injuries are summarised in the table below.

It can be seen that the number of lives saved increases from 723 in 2010 to 1,141 in 2020 when all vehicles use DRL[77].

Table 13-4 Study estimate of the effect of daytime running lights in selected years

Category	2010	2020
Fatalities	-723	-1,141
Severe injuries	-5,438	-9,545
Slight injuries	-27,843	-48,915

[77] Please note that the total number of fatalities is assumed to have declined at that time.

In TNO (unknown) it is estimated that the use of DRL will prevent 2,359 fatal injuries per year in EU-12 (EU-15 excluding Denmark, Finland and Sweden) when all vehicles use DRL. The main reason for the difference between the estimate obtained here and the results of the TNO-study are:

- The countries under consideration are different
- The rate of implementation is different.

When correcting for this the results of this study are rather similar to those of TNO.

13.7 Cost-benefit assessment

The results of the cost-benefit assessment are presented in the table below.

Table 13-5 Main results of CBA - Daytime running lights

Category	Net present value in 2005, million €
Accident costs	**32,057**
Fatalities	10,473
Severe injuries	11,814
Slight injuries	9,770
Total costs	**-15,880**
Unit related costs	-3,395
Extra bulb costs	-6,435
Extra fuel costs	-3,827
External costs	-4,273
Total net present value	**14,128**
Benefit/cost-ratio	**1.8**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

Benefits clearly exceed costs. The benefit/cost-ratio is estimated at 1.8, which is slightly above the TNO estimate of 1.55 for dedicated DRLs. For other scenarios for DRL, TNO estimate a benefit/cost-ratio of 1.42-1.96, so in general the figure presented here is in line with previous findings.

ETSC (2003) refers to a benefit/cost-ratio of 6.4 for special DRL lamps. The benefit assessment of ETSC (2003) is very similar to that of TNO (unknown). However the cost estimate of environmental costs and fuel cost is much lower compared to this study and the cost estimates of TNO (unknown).

The robustness of the results to the values used is therefore evaluated. The results of selected sensitivity analyses are shown in the table below.

Table 13-6 Results of sensitivity analyses - Daytime running lights

Sensitivity analysis	BCR
1. Low costs (-20%)	2.2
2. High costs (+20%)	1.5
3. Low effect on collision probability (see section 13.5)	0.7
4. High effect on collision probability (see section 13.5)	2.9
5. High market penetration rate in 2025 (25%)	1.7
6. Low average lifetime of vehicle (12 years)	1.7
7. High average lifetime of vehicle (16 years)	1.9

For all the values used in the sensitivity analyses, benefits exceed costs, except for the low estimates on effectiveness which are not supported by existing studies. The results are robust regarding assumptions about the market penetration rate in 2025 for the Do-nothing scenario and the assumed lifetime of the vehicle.

14 Technology 2.2: Conspicuity marking

14.1 Definition of technology

This study investigates the consequences of an obligatory introduction of "retro-reflective marking for heavy and long vehicles and their trailers".

According to UN/ECE-R 104 contour marking is applied to both the rear and lateral sides[78]. However, the assessment presented here is based on contour marking of the rear and only line marking on the lateral side[79].

The idea is that retro-reflective contour marking increases the visibility (recognition) over a wide range of distances and provides for an easy identification of certain vehicles.

The analysis assesses the costs and benefits of making conspicuity marking obligatory for HGV > 3.5 tons.

14.2 Accidents - Do-nothing scenario

The first part of the analysis is to determine the number of potentially avoidable accidents in EU-25.

Ideally, accidents according to following criteria should be identified[80]:

- Accidents which occurred at night-time or at dusk/dawn (lighting conditions = darkness or twilight)[81]
- Accidents which occur in streets where no street lights existed or where the street light were unlit
- Accidents which involve a HGV with a gross weight of more than 3.5 tons in such a way that another vehicle hit the HGV at the rear or at the side

[78] see www.unece.org/trans/main/wp29/wp29regs/r104e.pdf for exact definition
[79] Specified by DG TREN
[80] TÜV (2003, page 36-38)
[81] This might be conservative statements as it is sometimes stated that retro-reflective marking also increases the conspicuity of HGV in better lighting conditions.

– Accidents where the cause of the accident has been stated as "recognition too late" or "no recognition at all".

Data for such detailed segmentation is not available for the whole EU. However, on the basis of the principles outlined above, TÜV (2003) estimates the number of potentially avoidable personal damage accidents by means of contour marking of HGV>3.5 tons in EU-15. The numbers are presented in the table below.

Table 14-1 Potentially avoidable personal damage accidents by means of contour marking of HGV>3.5 tons in EU-15

	Fatal accidents	Fatalities	Serious injury accidents	Seriously injured persons	Slight injury accidents	Slightly injured persons
On motorways	57	73	222	372	455	762
Outside urban areas	73	94	285	477	555	929
Inside urban areas	5	6	32	54	145	243
Total	135	173	539	903	1,155	1,934

Source: TÜV (2003)

Given that the number of fatalities in EU-15 amounts to close to 39,000, approx. 0.4%-0.5% of the total fatalities are potentially avoidable by means of contour marking of HGV > 3.5 tons. Similar reasoning leads to the fact that approx. 0.2%-0.3% of the severe injuries and approx. 0.04%-0.05% of the slight injuries are potentially avoidable by means of contour marking.

The ratios used here are presented in the table below together with estimates on the number of potentially avoidable fatalities, severe injuries and slight injuries in 2010.

Table 14-2 Potentially avoidable fatalities, severe injuries and slight injuries by means of contour marking of HGV>3.5 tons in EU-25 in 2010

	Total number	Share of total which is potentially avoidable	Number of potentially avoidable
Fatalities	42,382	0.45%	170
Severe injuries	448,550	0.25%	1,121
Slight injuries	4,429,204	0.04%	1,772

Data shows that approx. 55% of the accidents are due to rear impacts, whereas the remaining 45% are the result of side impacts.

14.3 Scenario for implementation

As for the evaluation of most of the other technologies, the cost-benefit analysis is based on the assumption that it is made mandatory for all new vehicles (HGV >3.5 tons) to have the technology installed.

TÜV (2003) estimates that the share of HGV with retro-reflective marking is not higher than 5% at present. The results presented here are therefore based on the assumption that 5% of the HGV are currently equipped with retro-reflective marking. Given that no information is available on whether this ratio is expected to increase or decline in the future if nothing is done to promote retro-reflective marking, it is assumed that this figure is constant in the Do-nothing scenario.

A sensitivity analysis is made for a market deployment rate of 15% (high) in 2025 for the Do-nothing scenario.

The analysis is based on the fleet statistics for HGV presented in section 4.3.

14.4 Cost assessment

The costs of implementing contour marking according to UN/ECE-R 104 were estimated in TÜV (2003). Costs consist of material and labour costs. In TÜV (2003) the following cost estimates are applied for contour marking according to UN/ECE-R 104:

- Material costs= €300/ HGV (average costs)
- Labour costs= €190/HGV (average costs)[82]
- Total costs= €490/HGV (including VAT)
- Total costs= 408€/HGV (excluding VAT, assuming an average VAT-rate of 20%)

The cost figures represent an average for EU-15. In the NMS labour costs are lower. However, as the fleet of HGV is relatively smaller in the NMS, no correction has been made for lower labour costs in the NMS. Hence a cost figure of €408/HGV (excluding VAT) has been applied here.

However, it is taken into account that the lateral side will only have line marking (ref. section 14.1). According to the details given in TÜV (2003), the costs of contour marking the rear and only line marking the lateral sides will be around half of the costs of contour marking both the rear and the lateral sides

[82] Based on the assumption that it takes 4.5 hours to equip one vehicle and an average wage of €42/hour (TÜV (2003, page 51))

(estimate based on the use of conspicuity tape). Hence a cost estimate of €204/HGV (excluding VAT) is applied here.

The resulting net present value of the unit related costs is approx. €960 million, equivalent to annual costs of approx. €81 million (400,000 new vehicles with contour marking at a unit costs of approx. €200).

Furthermore, TÜV produces a rough estimate of average costs per HGV in case of enhanced distribution and equipment and lower material costs. This figure indicates that costs could potentially decline by approx. 43% (€233/HGV compared to €408/HGV). This is used to derive a minimum figure for the sensitivity analysis of €116/HGV.

It is difficult to estimate the exact life span of the retro-reflective material. The cost-benefit assessment presented here is based on the assumption that the average useful life span is equal to the lifetime of the vehicle[83]. To reflect this, the sensitivity analysis has been made with higher unit costs to reflect the potentially higher annual costs. The high unit cost estimate applied in the sensitivity analysis is €400/HGV (excluding VAT).

14.5 Safety impacts

Only little evidence exists on the effectiveness of retro-reflective marking of HGV. Field tests performed by the Laboratory of Lighting Technology at the Darmstadt University of Technology[84] show an effectiveness of 95% in reference to the narrow definition of relevant accidents.

However, it has to be taken into account that the line marking on the lateral sides is not as effective as full contour marking. It is assumed that the effectiveness is lowered by 20 percentage points for the side impacts (which accounts for 45% of total impacts). The adjusted effectiveness rates applied here are presented in the table below. As can be seen, it is assumed that the effectiveness is the same for all severity categories.

Table 14-3 Reduction in collision probability - Conspicuity marking

Fatalities	86% (75% - 100%)
Severe injuries	86% (75% - 100%)
Slight injuries	86% (75% - 100%)

Note: The estimated effectiveness is for a narrow definition of relevant accidents. Figures in brackets refer to min/max estimates for sensitivity analyses.

Theoretically conspicuity marking could have an effect on the severity of accidents if the accident occurs due a possible lower speed at collision. However,

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[83] TÜV estimate the costs for 2 scenarios: 1) average lifetime of 12 years, 2) half of the retro-reflective marking has a useful life of 12 years and half a useful life of 6 years.
[84] Reported in TÜV (2003)

this effect is not taken into account here, as none of the available studies provide estimates on this effect.

14.6 Accidents - Do-something scenario

On the basis of the estimate of the potentially avoidable personal damage accidents by means of contour marking of HGV>3.5 tons in EU-25, the estimated effect on collision probability and the rate of implementation of the number of avoided fatalities and injuries can be estimated. The results are presented in the table below for 2010 and 2020.

Table 14-4 Study estimate of the effect of conspicuity marking in selected years

Category	2010	2020
Fatalities	-78	-122
Severe injuries	-460	-800
Slight injuries	-727	-1.268

These figures are in line with figures presented in TÜV (2003).

14.7 Cost-benefit assessment

The results of the cost-benefit assessment are presented in the table below. As can be seen, benefits are estimated to exceed costs by a factor 2.5.

Table 14-5 Main results of CBA - Conspicuity marking

Category	**Net present value in 2005, million €**
Accident costs	**2,371**
Fatalities	1,123
Severe injuries	994
Slight injuries	254
Total costs (unit related)	**-960**
Total net present value	**1,411**
Benefit/cost-ratio	**2.5**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

The estimated benefit/cost-ratio is in line with the ratio presented in TÜV (2003) for EU-15. TÜV (2003) estimate the benefit/cost-ratio to be in the region of 1.44 to 3.57, depending on the unit costs for installation and the lifetime of the retro-flective material (for obligatory equipment of all newly registered HGV > 3.5 tons).

The main difference between the results presented in TÜV (2003) and the analysis presented here is that TÜV (2003) assess the consequences of contour marking on both the rear and lateral sides, whereas this study has assessed costs and benefits for contour marking on the rear and line marking on the lateral side.

The robustness of the results to the values used is therefore evaluated. The results of selected sensitivity analyses are shown in the table below.

Table 14-6 Results of sensitivity analyses - Conspicuity marking

Sensitivity analysis	BCR
1. Low unit costs for installation (€116/HGV)	4.3
2. High unit costs for installation (€400/HGV)	1.3
3. Low effect on collision probability (75%)	2.2
4. High effect on collision probability (100%)	2.9
5. High market penetration rate in 2025 (25%)	2.4
6. Low average lifetime of vehicle (12 years)	2.3
7. High average lifetime of vehicle (16 years)	2.7

For all the values used in the sensitivity analyses, benefits exceed costs.

15 Technology 2.3: Retro-fitting of blind spot mirrors

15.1 Definition of technology

The Commission has implemented a directive to make blind spot mirrors compulsory in new trucks. The focus here is to assess the possible consequences of extending the existing legislation to cover existing trucks.

More specifically the consequences of retro-fitting of wide angle/close proximity mirrors to existing goods vehicles over 3.5 tons are assessed here.

15.2 Accidents - Do-nothing scenario

The following accidents are considered relevant:

- Accidents where the fatalities are cyclists or motorcyclists (including moped riders)
- Accidents where the HGV is turning right

TRL (2004) estimates - on the basis of CARE statistics - that close to 9,000 pedestrians and 3,400 cyclists are killed per year in EU-25.

Likewise TRL (2004) estimates that 75,000-175,000 pedestrians and 49,000-115,000 cyclists are severely injured per year in EU-25.

No data is available for slight injuries.

Data for the Netherlands for 1996 - presented in Jacobs Consultancy (2004) - indicates that HGV were involved in 18.5% of fatal accidents with bicycle and moped riders. The corresponding figure for severe injuries is 3.4%.

Furthermore, data from TNO for the Netherlands in 1996- also presented in Jacobs Consultancy - shows that some 36% of total accidents in collisions between bicycles/mopeds and goods vehicles are "blind spot accidents", defined as goods vehicles turning right and cycles/mopeds going straight ahead.

If these figures are representative for the whole of EU-25, approx. 1.5% of all fatalities in EU-25 can be considered as cyclists/moped riders/pedestrians being killed by a HGV turning right. A similar figure is presented in TNO (1998) in a study on the situation in the Netherlands. For severe injuries the share appears to be slightly lower. Here a figure of 1.25% is used.

Due to a lack of the data the same figure is applied for slight injuries.

Furthermore, Belgium and the Netherlands have been excluded from the analysis, as all vehicles are assumed to be retro-fitted under the existing legislation.

The shares of relevant accidents used here are presented in the table below.

Table 15-1 Relevant accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-15	1.25%	1.25%	1.5%
NMS	1.25%	1.25%	1. 5%

15.3 Scenario for implementation

The Commission has, as mentioned, implemented a directive to make blind spot mirrors compulsory in new vehicles.

Hence the focus here is on the costs and benefits of retro-fitting of blind spot mirrors to existing HGV.

The analysis is based on the estimates of the size of the fleet of HGV > 3.5 tons, which were presented in section 4.3.

As described in section 4.3, the retro-fitting scenario is here defined as a scenario where it is made mandatory to retro-fit blind spot mirrors in 2007. This means that approx. 3.8 million HGV will have blind spot mirrors installed in 2007.

In comparison, Jacobs Consultancy (2004) estimated that 4.4 million HGV are available for retro-fitting of wide angle/close proximity mirrors in 2006. The difference can solely be explained by the fact that the retro-fitting here is assumed to take place in 2007 and not in 2006.

15.4 Cost assessment

In Jacobs Consultancy (2004) it was estimated that retro-fitting of blind spot mirrors would cost €150 for side-view mirrors. This figure is also used here.

This entails that retro-fitting of blind spot mirrors will result in a cost of €493 million (net present value in 2005).

To assess the sensitivity of the results of the cost-benefit assessment to the unit cost estimate, sensitivity analyses are made on the basis of a unit cost of €200 (high) and €100 (low).

15.5 Safety impacts

In SWOW (2004) it was estimated that the risk of collision could be reduced by 40% for the relevant accidents (see section 15.2) when a HGV is fitted with wide angle/close proximity mirrors, compared to the situation without blind spot mirrors. Almost the same estimate was used in Jacobs Consultancy (2004). This figure is also applied here for all accident categories (see table below).

Table 15-2 Reduction in collision probability - Blind spot mirrors

Fatalities	40% (20%-50%)
Severe injuries	40% (20%-50%)
Slight injuries	40% (20%-50%)

Note: Figures in brackets refer to min/max-values used in the sensitivity analysis

Blind spot mirrors have no effect on the severity of accidents if an accident occurs.

15.6 Accidents - Do-something scenario

The effect of retro-fitting of wide angle/close proximity mirrors to existing goods vehicles over 3.5 tons on the number of fatalities, severe injuries and slight injuries is presented in the table below.

For example, it can f be seen that retro-fitting of blind spot mirrors could save 89 lives in 2010. There is no effect in 2020, as all HGV > 3.5 tons will also have blind spot mirrors in 2020 if there is no retro-fitting[85], i.e. the number of HGV with blind spot mirrors is the same in the Do-something scenario and the Do-nothing scenario, which is here defined as compulsory implementation of blind spot mirrors in new vehicles.

Table 15-3 Study estimate of the effect of retro-fitting blind spot mirrors in selected years

Category	2010	2020
Fatalities	-89	0
Severe injuries	-782	0
Slight injuries	-7.717	0

[85] As all new vehicles will have blind spot mirrors from 2006 and the lifetime of a HGV is assumed to be 14 years.

15.7 Cost-benefit assessment

The results of the economic cost-benefit assessment for retro-fitting of blind spot mirrors are presented in the table below.

It can be seen that benefits are estimated to exceed costs by a factor 3.8.

Table 15-4 Main results of CBA - Retro-fitting of blind spot mirrors

Category	Net present value in 2005, million €
Accident costs	**1,873**
Fatalities	444
Severe injuries	551
Slight injuries	878
Total costs (unit related costs)	**-493**
Total net present value	**1,380**
Benefit/cost-ratio	**3.8**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

In comparison, Jacobs Consultancy (2004) estimate that benefits exceed costs by a factor 4 for retro-fitting of wide angle/close proximity mirrors to existing goods vehicles over 3.5 tons.

To analyse the robustness of the results to the values used, a range of sensitivity analyses were conducted. The results are shown in the table below.

It can be seen that the fact that benefits exceed costs is robust to the assumptions made, as the benefit/cost-ratio is above 1 for all the sensitivity analyses.

Table 15-5 Results of sensitivity analyses - Retro-fitting of blind spot mirrors

Sensitivity analysis	BCR
1. Low unit costs (€100)	5.7
2. High unit costs (€200)	2.8
3. Low effect on collision probability (see section 15.5)	1.9
4. High effect on collision probability (see section15.5)	4.7
5. Low average lifetime of vehicle (12 years)	3.2
6. High average lifetime of vehicle (16 years)	4.3

16 Technology 3.1: Intelligent speed adaptation (ISA)

16.1 Definition of technology

Intelligent speed adaptation (ISA) devices can be described as follows (depending on e.g. whether the system is advisory/supportive or compulsory/preventive):

"The system alerts the driver with audio, visual and/or haptic feedback when the speed exceeds a limit set by the driver or the legal speed limit. The speed limit information is either received from transponders in speed limit signs or from a digital road map, requiring reliable positioning information.[86]"

Further development of ISA devices include:

"Safe speed - adaptive maximum speed of the car systems are designed to maintain a safe speed, whether in relation to the road conditions and environment, or when approaching curves, congestion or adverse road conditions. Examples of these dynamic systems include curve speed prediction, traffic sign recognition, speed advice, road status, and intersection support using vehicle-infrastructure communication. It is possible to have systems linked to intelligent speed adaptation, based on satellite positioning or vehicle-infrastructure communications or a combination of the two, which will alert drivers to the speed limit according to the current traffic situation"[87].

In this study the potential of intelligent speed adaptation to observe the given speed limit by e.g. digital map based systems, and of the more advanced dynamic adaptation systems to maintain a safe speed under different road and traffic conditions, is assessed. Manually set devices equal part of the function of adaptive cruise control systems and are therefore part of the system effect described in chapter 12.

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[86] eSafety Forum Working Group (2005, page 10)
[87] VDI/VDE/IT, IFV Köln (2005, page 41)

16.2 Accidents - Do-nothing scenario

Intelligent speed adaptation devices are targeted at reducing the risk of rear end and head on collisions, merging and intersection collisions, vehicle-pedestrian collisions and left roadway accidents[88].

SAFETYNET (2005, page 44) shows that approximately 35-60% of fatalities registered in 11 of the EU-15 countries are in rear end, head on or other types of collisions, while another 40% happen in single accidents.

Research in the UK and Germany shows that inappropriate speed is a factor in 25-33% of all road accidents[89]. Three in-depth studies of fatal and severe injury accidents in Denmark with young car drivers, on motorways and with vans show that speed has been a factor contributing either to the accident risk or severity in 40-80% of the investigated accidents[90].

The distribution shown in Table 16-1 is estimated on the basis of the above information.

Table 16-1 Share of injuries in relevant accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-15	50%	50%	50%
NMS	50%	50%	50%

16.3 Scenario for implementation

The largest study so far of intelligent speed adaptation was carried out in Sweden with 5,000 equipped vehicles and 10,000 drivers. The system was advisory with a combination of audio, visual and haptic feedback[91].

Currently ISA systems are still being tested and more knowledge/experience is needed[92]. Questions regarding voluntary or mandatory equipment, type of speed limits, road categories and vehicle types to include, road users to use ISA, etc. remain to be answered. The necessary information infrastructure has to be made available. Estimated market penetration in new cars in the "business as usual" scenario is given as very low in 2005 (0-5%), low in 2010 (5-20%) and medium in 2020 (20-50%). In an EU support scenario the market penetration is expected to be medium in 2010 and high in 2020 (50-80%)[93].

88 VDI/VDE/IT, IFV Köln (2005, page 26)
89 eSafety Forum Working Group (2002, page 22-23)
90 Havarikommissionen (2002, 2003 and 2005)
91 Safety Forum Working Group (2002, page 34) and Vägverket (2002a, page 1-14)
92 Vägverket (2002a, page 123-124)
93 eSafety Forum Working Group (2002, page 13-15)

Based on this the expected market penetration used in this study can be seen in Table 16-2.

Table 16-2 Market penetration - Intelligent speed adaptation

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	0%	20%
Do-something	0%	100%

Note: "Market deployment in 2006" refers to X in figure. "Market deployment in 2020" for the Do-nothing scenario refers to Y in figure.

Sensitivity analyses are made for a market deployment rate of 10% (low) and 40% (high) in 2025 for the Do-nothing scenario.

16.4 Cost assessment

Intelligent speed adaptation systems are presently not standard equipment, which reflects on costs. An ISA system (to observe speed limit) currently costs approximately €500-2,000 per unit. The price is expected to drop significantly if a greater market develops. The Swedish ISA project states a user willingness to pay €30-100 per unit[94].

The main analysis is based on the assumption that unit costs are €500 per unit. However, as the cost estimates are highly uncertain, the benefit/cost-ratio is also estimated for unit costs of €250 and €2,000.

No information is available on the cost of dynamic adaptation systems (to maintain safe speed).

To the unit price must be added costs of providing e.g. the necessary communication infrastructure that will be dependent on system choice. This is not taken into account here, as no solid cost estimates applicable to EU-25 is available.

16.5 Safety impacts

eSafety Forum Working Group (2005) states that the SpeedAlert (advisory) system can reduce injury accidents by 10-20% and fatal accidents by 17-18%. Trials with ISA in Sweden have shown that its universal use could reduce injuries by up to 20-25% (in urban areas). A summary even mentions effects of 20-30% savings.

Other research has concluded that a dynamic ISA system which prevents drivers from exceeding the speed limit and applies temporary limitations to maximum speed due to congestion, fog, slippery road surfaces, major accidents, out-

[94] Vägverket (2002a, page 114-121)

side schools at drop-off times, etc. could reduce injury accidents by 36% and fatal accidents by 59%[95].

It is estimated that ISA could prevent 11-38% of all accidents in Spain, 17-51% of all severe injuries and 22-61% of fatalities (lower value corresponding to advisory system with fixed speed limits, and upper value corresponding to compulsory systems with dynamic speed limits)[96]. TØI has calculated that intelligent speed adaptation (to observe speed limits) can reduce fatalities by 20% in Norway and 33% in Sweden[97].

eSafety Forum Working Group (2005) has asserted that speed warning could reduce fatalities by-10-12,000 per year in EU-15, corresponding to 25-30% of all fatalities in EU-15[98].

Based on the above this study expects ISA systems (like the Swedish advisory/supportive model) to reduce accidents and injuries as presented in Table 16-3. The effect of implementing a compulsory dynamic system will be markedly higher.

Given that ISA systems are estimated to influence 50% of total accidents, the unit effect is a factor 2 above the reductive potential for all accidents.

Table 16-3 Reduction in collision probability - Intelligent speed adaptation

	Change in risk of accident
Fatalities	50% (40%-60%)
Severe injuries	40% (30%-50%)
Slight injuries	40% (30%-50%)

Note: Figures in brackets refer to min/max-values used in the sensitivity analyses

ISA will have no impact on the severity of accidents if they occur.

16.6 Accidents - Do-something scenario

The effects of intelligent speed adaptation systems on the number of fatalities and injuries are summarised in Table 16-4.

Intelligent speed adaptation systems can reduce the risk of speed related road accidents. It is thus estimated that EU implementation of ISA systems (to observe speed limits) can save 5,171 lives in 2010 and 6,807 lives in 2020, when all vehicles have installed the required equipment. Corresponding figures for reductions in severe and slight injuries appear in the table below.

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[95] eSafety Forum Working Group (2005, page 13 & 34), Vägverket (2002a, page 15-18 & 31-52) and Vägverket (2002b)

[96] CARS21 (2005a, page 1-2)

[97] Elvik (2005)

[98] eSafety Forum Working Group (2002, page 23)

Table 16-4 Study estimate of the effect of intelligent speed adaptation in selected years

Category	2010	2020
Fatalities	-5,171	-6,807
Severe injuries	-44,540	-65,877
Slight injuries	-439,227	-650,469

16.7 Cost-benefit assessment

The result of the cost-benefit analysis of intelligent speed adaptation systems is presented in Table 16-5 . The result for the more advanced dynamic adaptation system to maintain safe speed has not been calculated, as no unit cost estimates are available. However, it is evident that such a system is also likely to be feasible, as benefits are much higher.

Table 16-5 Main results of CBA - Intelligent speed adaptation

Category	**Net present value in 2005, million €**
Accident costs	**293,698**
Fatalities	67,460
Severe injuries	87,249
Slight injuries	138,990
Total costs	**-88,016**
Unit related costs	-88,016
Total net present value	**205.682**
Benefit/cost-ratio	**3.3**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

In comparison, TØI has calculated a benefit/cost-ratio of between 0.6-0.9 for implementation of intelligent speed adaptation (to observe speed limit) in Norway and Sweden[99].

The main reason why the benefit/cost-ratio is higher in this study than in the TØI study is, according to Elvik (2005), likely to be the fact that increased travel time due to reduced speed is included as a negative benefit in the TØI study. Besides, the share of relevant accidents may be lower in the TØI study which probably uses detailed Norwegian and Swedish accident data. This study is primarily based on general EU data.

The results of selected sensitivity analyses are shown in the table below.

[99] Elvik (2005)

Table 16-6 Results of sensitivity analyses - Intelligent speed adaptation

Sensitivity analysis	BCR
1. Low unit costs (€250)	6.7
2. High unit costs (€2000)	0.8
3. Low effect on collision probability (see section 16.5)	2.6
4. High effect on collision probability (see section 16.5)	4.0
5. Low market penetration rate in 2025 (10%)	3.4
6. High market penetration rate in 2025 (40%)	3.1
7. Low average lifetime of vehicle (12 years)	3.0
8. High average lifetime of vehicle (16 years)	3.6

For all the values used in the sensitivity analyses, benefits exceed costs, except for the high unit cost estimate. The results are robust regarding assumptions about the market penetration rate in 2025 for the Do-nothing scenario and the assumed lifetime of the vehicle.

17 Technology 4.1: Seat belt reminders

17.1 Definition of technology

Seat belt reminders can be described as follows:

"A seat belt reminder (SBR) system is based on small detectors mounted in the seats. These inform the system if the seat is occupied and whether the seat belt is fastened or not. The system alerts the vehicle occupants by means of e.g. sound and visual indications or restricts vehicle movement with an ignition interlock function when a seat belt should be worn. The seat belt reminder system can be installed in both the front seats and the rear seats."

In this study two different types of seal belt reminder systems (including both front and rear seat occupants) are assessed:

Indicative version of SBR
In the indicative version of the system, a distinct visual and/or audio signal turns on when the car is started and the seat belt is not buckled in an occupied seat. This version is already implemented in a number of car types in the EU.

Blocking version of SBR
In the more restrictive blocking version of the SBR system, the car cannot start or be driven unless the seat belts are fastened for all occupied seats. This system has not been implemented in any vehicles yet.

17.2 Accidents - Do-nothing scenario

The use of seat belts does not affect the number of accidents, only the probability of being injured when an accident occurs. Similarly, seat belt reminders do not hinder accidents, but are targeted at reducing the severity of driver and passenger injuries in vehicles. Thus, in principle seat belt reminders are relevant for all accidents involving vehicles.

In practice, seat belt reminders will only have an influence on accident consequences for the drivers and passengers not wearing seat belts.

Statistics show that in EU-15, approx. 80% of the front seat drivers and passengers use seat belts. For the rear seat the wearing rate is markedly lower and more varying. On average it is less than 50%[100]. For the new member states analogue data is lacking, but it is estimated that seat belt usage is lower in NMS than in EU-15. It is thus assumed that the average rate of seat belt use in the new member states is on level with the countries in EU-15 with the lowest rate of front and rear seat belt usage.

The numbers used in this analysis are presented in Table 17-1.

Table 17-1 Use of seat belts in EU-15 and the NMS

	Use of seat belts (front/rear)
EU-15	80%/50%
NMS	50%/10%

Seat belts only affect the road users inside the vehicle in case of an accident. SAFETYNET (2005) indicates that approx. 66% of all fatalities are car occupants. 85% of these are front seat occupants, and 15% are rear seat occupants[101].

In addition it has been taken into account that drivers not wearing seat belts are more often involved in fatal accidents than drivers wearing seat belts. This indicates that drivers who use seat belts have a lower accident rate than drivers who do not[102]. Danmarks Transportforskning (2002, page 36) thus states that although only 10-20% of drivers do not wear a seat belt, they are involved in almost 50% of all fatal accidents. Similarly ETSC (2003) assumes that 50% of front seat occupant fatalities did not wear seat belts.

Based on this information, it is estimated that the potential for influencing accidents and injuries by seat belt reminders is as shown in Table 17-2.

Table 17-2 Share of injuries in relevant accidents of all road accidents

	Slight injuries	Severe injuries	Fatalities
EU-15	13%	13%	33%
NMS	33%	33%	50%

17.3 Scenario for implementation

The scenarios for implementation for the two systems are presented below.

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[100] ICF (2003, page 28-33) and ETSC (2003, page 29)
[101] ETSC (2003, page 30)
[102] Elvik and Vaa (2004, page 673-683)

Indicative version of SBR
The indicative version of the seat belt reminder system is already installed in a number of new cars. For example, approx. 5% of the car fleet in Spain is equipped with SBR[103]. Due to a lack of better data it is assumed here that the indicative version of SBR is installed in 10% of the current fleet of vehicles in EU-25[104].

This share is expected to increase over the coming years, even if nothing extraordinary is done to further promote the indicative version of seat belt reminders, as it is already standard equipment in many new vehicles.

None of the available studies provide projections on the future level of market penetration. It is pragmatically assumed in this study that SBR will be installed in 90% of fleet in 2025[105] as shown Table 17-3.

Table 17-3 Market penetration for the indicative version of SBR

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	10%	90%
Do-something	10%	100%

Sensitivity analyses are made for a market deployment rate of 50% (low) and 100% (high) in 2025 for the Do-nothing scenario.

Blocking version of SBR
Correspondingly it is assumed that no cars have or will have the blocking version of SBR installed if nothing extraordinary is done to promote or impose the system (see table below).

Table 17-4 Market penetration for blocking version of SBR

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	0%	0%
Do-something	0%	100%

Sensitivity analyses are made for a market deployment rate of 20% (high) in 2025 for the Do-nothing scenario.

[103] CARS21 (2005a)
[104] Indicated by stakeholder that a figure of 5% in not representative for EU-25.
[105] Indicated by stakeholder

17.4 Cost assessment

The seat belt reminder system is a relatively simple system. Hence, costs are relatively low. The cost figures used here are presented in Table 17-5.

According to the Transportation Research Board (2003), the total cost of a blocking version of the system will be approx. €55 for large-scale production. For aftermarket applications, unit costs are about 3 times as high.

The costs of the indicative version are expected to be lower as the interlock system is saved. ETSC (2003, page 29), however, states a cost of €60 for an indicative system covering only the front seats. Based on this limited information the following estimations of costs are used in this study.

Table 17-5 Costs of seat belt reminders (€ per vehicle)

Cost category	Best estimate	Minimum	Maximum
Indicative version	50	40	60
Blocking version	60	50	70

17.5 Safety impacts

The safety impacts of the indicative and blocking versions of seat belt reminders are presented below.

Indicative version
For the evaluation of the indicative version of seat belt reminders, it has to be taken into account that this system will not make all persons use the seat belt.

A Swedish study has concluded that an indicative SBR for the front seats can raise belt wearing among front seat occupants to a maximum of 97%, thus the remaining 3% of car drivers and front seat passengers will remain unbelted[106]. For want of better data it is assumed that a SBR system will raise rear seat belt wearing to about the same level. In this scenario it is estimated that remaining unbelted occupants will make up approx. 5-10% of all car fatalities and injuries.

According to Elvik and Vaa (2004), the use of seat belts reduces the fatalities for drivers by 50%, front seat passengers by 45% and rear seat passengers by 25%. The effect on severe injuries is correspondingly 45%, 45% and 25 %, while slight injuries are reduced by 25%, 20% and 20% respectively.

Based on a weighting with the mentioned distribution of front and rear seat fatalities, effects on accident severity are calculated as shown in Table 17-6.

[106] ETSC (2003, page 29-32)

Table 17-6 Accident severity matrix - Indicative version

Share of accidents changing type	After Fatalities	Severe injuries	Slight injuries	Avoided
Fatalities changing to…		43% (30%-50%)	0%	0%
Severe injuries changing to…	0%		39% (30%-50%)	0%
Slight injuries changing to…	0%	0%		22% (15%-30%)

Note: Figures shows a weighted average for front and rear seat. Figures in brackets refer to min/max-values used in the sensitivity analyses.

Blocking version
If the blocking version of SBR is implemented, it is assumed that all car occupants will wear a seat belt - despite the fact that some studies mention that some drivers refuse to use the seat belt and are willing to somehow uninstall the system.

Thus the weighted effect on accident severity is as presented in Table 17-7.

Table 17-7 Accident severity matrix -Blocking version

Share of accidents changing type	After Fatalities	Severe injuries	Slight injuries	Avoided
Fatalities changing to…		46% (35-55%)	0%	0%
Severe injuries changing to…	0%		42% (30-50%)	0%
Slight injuries changing to…	0%	0%		24% (15-30%)

Note: Figures shows a weighted average for front and rear seat. Figures in brackets refer to min/max-values used in the sensitivity analyses.

17.6 Accidents - Do-something scenario

The effects of indicative and blocking seat belt reminder systems on the number of fatalities and injuries are summarised in Table 17-8 and Table 17-9.

SBR systems cannot reduce the accident risk, but reduce the severity of injuries to car occupants in case of accidents.

Indicative version
It is estimated that EU implementation of indicative seat belt reminders can save 1,023 lives in 2010 and 524 lives in 2020, when all vehicles have installed the required equipment. Corresponding figures for reductions in severe and slight injuries are presented in the table below.

Table 17-8 Study estimate of the effect of seat belt reminders - Indicative version in selected years

Category	2010	2020
Fatalities	-1,023	-524
Severe injuries	-3,262	-1,915
Slight injuries	-18,856	-10,788

Blocking version
Implementation of blocking seat belt reminders can similarly save 3,771 lives in 2010 and 5,809 lives in 2020.

Table 17-9 Study estimate of the effect of seat belt reminders - Blocking version in selected years

Category	2010	2020
Fatalities	-3,771	-5,809
Severe injuries	-12,123	-21,431
Slight injuries	-71,046	-122,406

17.7 Cost-benefit assessment

The results of the economic cost-benefit assessment for seat belt reminders are presented below.

Indicative version
The results of the indicative version of SBR are presented in Table 17-10. The benefits of installing indicative seat belt reminders in all new vehicles are estimated to outweigh the costs by a factor 7.6.

Table 17-10 Main results of CBA - Seat belt reminders - Indicative version

Category	Net present value in 2005, million €
Accident costs	**17,240**
Fatalities	9,053
Severe injuries	4,254
Slight injuries	3,933
Total costs (unit related)	**-2,262**
Total net present value	**14,978**
Benefit/cost-ratio	**7.6**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

The robustness of the results to the values used is evaluated. The results of selected sensitivity analyses are shown in the table below.

It can be seen that the benefits are larger than the costs for all the sensitivity analyses.

Table 17-11 Results of sensitivity analyses - Seat belt reminders - Indicative version

Sensitivity analysis	BCR
1. Low unit costs (€40)	9.5
2. High unit costs (€60)	6.4
3. Low effect on accident severity (see section 17.5)	5.4
4. High effect on accident severity (see section 17.5)	9.5
5. Low market penetration rate in 2025 (50%)	7.2
6. High market penetration rate in 2025 (100%)	9.5
7. Low average lifetime of vehicle (12 years)	6.6
8. High average lifetime of vehicle (16 years)	9.4

Blocking version

For the blocking version the benefit/cost-ratio is even higher, as the higher effectiveness of the system more than outweighs the extra costs. The benefit/cost-ratio is estimated at 8.2 for the blocking version of seat belt reminders.

Table 17-12 Main results of CBA - Seat belt reminders - Blocking version

Category	**Net present value in 2005, million €**
Accident costs	**104,916**
Fatalities	53,833
Severe injuries	26,455
Slight injuries	24,629
Total costs (unit related costs)	**-12,753**
Total net present value	**92,164**
Benefit/cost-ratio	**8.2**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

The robustness of the results to the values used is evaluated. The results of selected sensitivity analyses are shown in the table below.

It can be seen that also for the blocking version, benefits are larger than costs for all the sensitivity analyses.

Table 17-13 Results of sensitivity analyses - Seat belt reminders - Blocking version

Sensitivity analysis	BCR
1. Low unit costs (€50)	9.9
2. High unit costs (€70)	7.1
3. Low effect on accident severity (see section 17.5)	5.8
4. High effect on accident severity (see section 17.5)	10.0
5. High market penetration rate in 2025 (20%)	7.7
6. Low average lifetime of vehicle (12 years)	7.5
7. High average lifetime of vehicle (16 years)	8.9

18 Technology 5.1: Tyre pressure monitoring systems

There are a large number of possible on-board, electronic testing devices. In fact all functions that are tested during roadworthiness testing could potentially be tested electronically on-board. The potential systems include tyre pressure monitoring, testing of brakes, testing of lights, the direction of indicators, the functioning of the air bags etc.

It is outside the scope of this project to test all these systems - and possibly also impossible, as data is not available for most of the systems (some of which do even not exist yet).

The focus in this chapter is on tyre pressure monitoring systems. Brake measurement devices are discussed later.

18.1 Definition of technology

Tyre pressure monitoring systems are an on-board technology which automatically test the inflation pressure of the tyres.

18.2 Accidents - Do-nothing scenario

Tyre pressure monitoring systems will only have an impact on the accidents caused by tyre pressure problems. Unfortunately, data is not readily available for EU-25, but TÜV (2003) gives an indication of the share of accidents related to tyre pressure problems for the US and Germany.

TÜV (2003) shows that, based on the official German road accident statistics, only 0.34% of accidents are categorised as "tyre-related". However, TÜV (2003) argues that this represents a large underestimation. The correction factor applied is based on studies from the Medical University of Hannover which shows that approx. 2.5% of all accidents are due to tyre-related problems. Tyre-related problems cover many types of problems, including inadequate maintenance (over-aging, tread wear, etc.), puncturing, pressure problems, etc. For this analysis, only tyre-related accidents caused by pressure problems are relevant. Based on studies from the Medical University of Hannover and

DEKRA[107] it is estimated that 3.3% of the tyre-related accidents are related to tyre pressure problems. Due to a lack of more precise data it is assumed here that these figures also apply for EU-25.

On the basis of this, the number of potentially avoidable fatalities, severe injuries and slight injuries can be estimated. The figures are presented in the table below for 2010.

Table 18-1 Potentially avoidable fatalities, severe injuries and slight injuries - Tyre pressure monitoring systems.

	Total	Tyre-related	Tyre-related caused by tyre pressure problems
Fatalities	42,382	1,059	35
Severe injuries	448,550	11,214	370
Slight injuries	4,429,204	110,730	3,654

Source: CARE, own calculations based on estimates from TÜV (2003)

18.3 Scenario for implementation

Very few cars have electronic tyre pressure monitoring systems. Unfortunately none of the available studies provide precise information on the market penetration rate. Hence the main analysis here is based on the simple assumption that none of the vehicles have the system installed - and that no vehicles will have the system installed if nothing extraordinary is done to promote the use of the system. To test the robustness of the results to the assumed scenario of implementation, sensitivity analyses are made for different scenarios. As will be apparent from section 18.7, the assumed level of market penetration is of little importance to the overall results.

18.4 Cost assessment

The cost information on tyre pressure monitoring systems is rather sparse. However, in the NHTSA study, the aftermarket price per system is indicated to be approx. $200-300 per system given the current level of production. Most manufacturers however indicate the costs of integrated TPMS to be under $75 per vehicle for large supply volumes.

In TÜV (2003) it is estimated that costs are in the range of €200-600 for an active TPMS for small/medium scale production. For large-scale production it is assumed that prices will decline by 5% p.a.

The study is based on the assumption that the costs are somewhere between the current price and the estimated large supply prices. Hence the main analysis is

[107] Deutscher Kraftfahrzeug-Überwachungsverein e.V. / Technical Inspection Assiciation (Germany)

based on the assumption of an integrated TPMS cost of €125 per vehicle. Due to the large uncertainty on the cost estimates, sensitivity analyses have been performed for a price of €75 per vehicle (low) and €250 per vehicle (high).

The battery life of the current PSB sensors is, according to the NHTSA, 7 to 10 years and replacement costs are approx. $10 to $20. The main analysis is based on the assumption of a lifetime of 7 years and a replacement cost of €15.

The aggregate cost estimate is presented in the table below.

Table 18-2 Aggregate cost estimate - Tyre pressure monitoring system

Category	Net present value in 2005, million €
Installation costs	26,568
Replacement costs	4,415
Total	**30,713**

18.5 Safety impacts

In TÜV (2003) it is assumed that all accidents related to tyre pressure problems can be avoided when implementing a tyre pressure monitoring system. This seems to be a rather optimistic assumption, but due to a lack of other data, the same assumption has been made here (see table below).

Table 18-3 Reduction in collision probability - Tyre pressure monitoring systems

Fatalities	100% (75%)
Severe injuries	100% (75%)
Slight injuries	100% (75%)

Note: For tyre-related accidents caused by pressure problems. Figures in brackets refer to min -values used in the sensitivity analyses

Tyre pressure monitoring systems will naturally not have any effect on the severity of accidents if the accidents occurs.

18.6 Accidents - Do-something scenario

The effects on the number of fatalities and injuries are summarised in the table below.

It is estimated that EU implementation of tyre pressure monitoring systems can save 18 lives in 2010 and 29 lives in 2020 when all vehicles have installed the required equipment. Corresponding figures for reductions in severe and slight injuries appear in the table below.

Table 18-4 Study estimate of the effect of tyre pressure monitoring systems in selected years

Category	2010	2020
Fatalities	-18	-29
Severe injuries	-196	-340
Slight injuries	-1,932	-3,369

18.7 Cost-benefit assessment

The results of the cost-benefit assessment are presented in the table below.

Table 18-5 Main results of CBA - Tyre pressure monitoring systems

Category	**Net present value in 2005, million €**
Accident costs	**1,363**
Fatalities	265
Severe injuries	423
Slight injuries	675
Total costs	**-30,713**
Unit related costs	-26,568
Replacement costs	-4,145
Total net present value	**-29,351**
Benefit/cost-ratio	**0.04**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

As can be seen, costs greatly exceed benefits, although it is assumed that all potential accidents are avoided if all vehicles have an active TRMS. The benefit/cost-ratio is estimated at 0.05, which is in line with the findings of TÜV. TÜV estimate a benefit/cost-rate of 0.0185-0.0554 depending on the price of the system.

The robustness of the results to the values used is therefore evaluated. The results of selected sensitivity analyses are shown in the table below.

Table 18-6 Results of sensitivity analyses - Tyre pressure monitoring systems

Sensitivity analysis	BCR
1. Low unit costs (€75)	0.07
2. High unit costs (€250)	0.02
3. Low effect on collision probability (75%)	0.04
6. High market penetration rate in 2025 (25%)	0.04
7. Low average lifetime of vehicle (12 years)	0.04
8. High average lifetime of vehicle (16 years)	0.05

For all the values used in the sensitivity analyses, costs exceed benefits by a large margin.

19 Technology 6.1: Alcohol ignition interlocks

19.1 Definition of technology

The alcohol ignition interlock can be described as follows[108]:

"The system checks the alcohol intoxication of the driver (breath test) when starting the vehicle and prevents the start of the vehicle when driver is intoxicated. During driving the system also checks intoxication at specific intervals and takes preventive actions with pre-warning."

19.2 Accidents - Do-nothing scenario

Alcohol ignition interlocks are targeted at reducing accidents with a least one drunk driver involved. In the EU the legal blood alcohol content (BAC) in most countries is 0.5 mg/ml. A few countries have a higher limit of 0.8 or a lower limit of 0.2 or 0.0 mg/ml. Some countries have different limits for specific road user target groups, e.g. novice or professional drivers[109].

In ICF (2003, page 22-27), the values given for drink driving related fatalities range between 3-42% for the individual countries in EU-15. SWOV (2001, page 13) mentions that 20% of total serious and fatal injury accidents are related to drink driving. A study on road safety in Sweden, the UK and the Netherlands estimates drink driving fatalities at 10-20%[110]. In Denmark fatalities in drink driver accidents made up 29% in 2002[111].

ETSC (2003, page 20-28) maintains that the number of fatalities over the BAC limit is underreported in the accident registration in all EU member states. It is estimated in this connection that 2% of journeys in EU-15 (in some countries less, some more) are associated with an illegal BAC. An average of 2% drink drivers will result in more than 25% of all driver injuries and approx. 40% of driver fatalities[112]. In the new member states the level of infringement is expected to be higher. It is conservatively estimated in this study that an average

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108 eSafety Forum Working Group (2005, page 9)

109 SWOV (2001, page 46-56)

110 SUNFLOWER (2002, page 41-54)

111 Danmarks Statistik (2003, page 24-29)

112 ETSC (2003, page 20-28)

3% of journeys in NMS involve drink drivers, which is in line with indications in ETSC (2003) for the high-level countries in EU-15. According to ETSC (2003), this results in at least 30% of all road injuries and 40% of fatalities.

It has to be kept in mind that a relatively smaller proportion of the drink driving population are responsible for a very large part of alcohol related fatalities and injuries. This hard core group consists of e.g. drivers with high BAC and the repetitive offenders. ETSC (2003) has shown that less than 0.5% of the driving population are involved in more than 20% of the serious road injuries.

Based on the above it is estimated in this study that the potential for influencing accidents and injuries from implementation of alcolocks in all vehicles is as seen in Table 19-1. If alcolocks are only introduced for hard core offenders, the target group is probably approx. 20-25% of all road injuries, depending on the national levels of enforcement.

Table 19-1 Share of injuries in drink driving accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-15	25%	25%	30%
NMS	35%	35%	40%

19.3 Scenario for implementation

Alcohol ignition interlocks have been introduced in the US, Canada and Australia. Most programmes are based on voluntary use by (repeat) drink driving offenders; fewer are based on mandatory participation. Participation rates are generally low. Tests with alcolocks are ongoing in the EU. Among others a feasibility study has been undertaken for the European Commission[113].

Current market penetration in the EU is assessed to be (close to) nil. The attitude towards drink driving and the support for alcolocks vary from country to country[114], thus the EU development until 2025 in the Do-nothing scenario is difficult to appraise. In this study it is estimated that 10% of the cars/vehicle-kilometres will be affected by voluntarily or mandatorily installed alcohol ignition interlocks in 2025 (see Table 19-2).

Table 19-2 Market penetration - Alcohol ignition interlocks

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	0%	10%
Do-something	0%	100%

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[113] SWOV (2001, page 13, 35-39)
[114] SWOV (2001, page 39-40)

Sensitivity analyses are made for a market deployment rate of 0% (low) and 25% (high) in 2025 for the Do-nothing scenario.

19.4 Cost assessment

The cost of a standard alcohol ignition interlock is given at €1,500. The price could drop to between €300 and €500 if the interlocks are mass-produced[115].

SWOV (2001) mentions a unit price of $1,000 per year for instalment and maintenance. In a Swedish pilot project, total costs of participation are €4,500 for a 2-year period[116].

This study is based on a unit price of €500. Sensitivity analyses are however also made on the basis of a unit cost of €300 (low) and €1,500 (high).

To this should be added the cost of control of and follow-up on potential malfunction, misuse and other problems hindering the purpose of the system. This is however not taken into account here.

19.5 Safety impacts

A rough estimate of the effect of alcohol ignition interlocks is given by the eSafety Forum Working Group (2005). Alcolocks are expected to reduce accidents with at least one drunk driver by 18%, provided that the system has been implemented in 70% of the car fleet/vehicle-kilometres. The total reductive potential of alcolocks is 25%. Regarding fatalities, the reductive potential of alcolocks is approx. 18%[117].

Another source states that 4,700 lives could be saved annually if a reduction in drink-driving (out of a total potential of 7,500, corresponding to 63%) were to occur. Canadian experience shows an effect of a 60% accident and injury reduction[118]. American experience analogously shows that alcohol ignition interlocks can lead to a 40-95% reduction in the rate of drink driving repeat offences[119].

SWOV (2001, page 30-34) mentions reductive effects of 28-65% on repeated drink-driving. The positive effects are only valid as long as the alcolock is installed. After removal, recidivism rates seem to equal non-user groups. Some studies may indicate more long-term positive effects, however. To maintain the effect after removal, alcolocks have to be supplemented with e.g. rehabilitation programmes aimed at improving driver behaviour and reducing re-offence rates.

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115 Indicated during stakeholder consultations

116 SWOV (2001, page 35-39)

117 eSafety Forum working Group (2005, page 40, 43-44)

118 The Danish Road Safety Council (2005a)

119 Indicated during stakeholder consultations

Conversely Elvik (2005) has calculated that alcohol ignition interlocks can only reduce total fatalities by 2% in Norway and 1% in Sweden - if used only for convicted offenders.

In this study alcolocks are expected to be permanently installed in all new vehicles. The estimated effects on accident probability are presented in Table 19-3. Alcolocks will have no effect on the severity of accidents if an accident occurs.

Table 19-3 Reduction in collision probability - Alcohol ignition interlocks

Fatalities	75% (50%-85%)
Severe injuries	75% (50%-85%)
Slight injuries	75% (50%-85%)

Note: Figures in brackets refer to min/max-values used in the sensitivity analyses

19.6 Accidents - Do-something scenario

The effects of alcohol ignition interlocks on the number of fatalities and injuries are summarised in Table 19-4.

It is estimated in this study that alcolocks can reduce the potential of drink driver related accidents. It is thus estimated that EU implementation of alcohol ignition interlocks can save 4,971 lives in 2010 and 7,152 lives in 2020, when all vehicles have installed the required equipment. Corresponding figures for reductions in severe and slight injuries appear in the table below.

Table 19-4 Study estimate of the effect of alcohol ignition interlocks in selected years

Category	2010	2020
Fatalities	-4,971	-7,152
Severe injuries	-43,252	-69,751
Slight injuries	-423,102	-684,418

19.7 Cost-benefit assessment

The results of the cost-benefit analysis of alcohol ignition interlocks are presented in Table 19-5.

Table 19-5 Main results of CBA - Alcohol ignition interlocks

Category	Net present value in 2005, million €
Accident costs	**298,575**
Fatalities	68,214
Severe injuries	89,217
Slight injuries	141,144
Total costs (Unit related)	**-97,144**
Total net present value	**201,431**
Benefit/cost-ratio	**3.1**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

As can be seen, it is estimated that the benefits of installing alcohol ignition locks in all new vehicles outweigh the costs by a factor 3.

In comparison, Elvik (2005) has calculated a benefit/cost-ratio of between 3.0-4.2 for implementation of alcolocks in Norway and Sweden.

This corresponds well with the general calculations for EU-25 in this study. Although no specific information on the calculation basis for Elvik (2005) is available, this apparent consistency probably hides the fact that the expected effect on, and possibly also the share of, drink driver accidents is higher in this study based on general EU accident data, while costs are lower, as only unit costs are included. Furthermore, the applied unit costs for accidents are likely to be lower in this study than in Elvik (2005).

The robustness of the results to the values used is evaluated below. The results of selected sensitivity analyses are shown in the table below.

For all the values used in the sensitivity analyses, benefits exceed costs, except for the high unit cost estimate.

Table 19-6 Results of sensitivity analyses - Alcohol ignition interlocks

Sensitivity analysis	BCR
1. Low unit costs (€300)	5.1
2. High unit costs (€1,500)	1.0
3. Low effect on collision probability (50%)	2.1
4. High effect on collision probability (85%)	3.5
5. Low market penetration rate in 2025 (0%)	3.2
6. High market penetration rate in 2025 (25%)	2.9
7. Low average lifetime of vehicle (12 years)	2.8
8. High average lifetime of vehicle (16 years)	3.1

Finally it should be mentioned that there are certain obstacles to the implementation of alcohol ignition interlocks in all new vehicles. For example, acceptance by law-abiding drivers could be a problem.

20 Technology 6.2: Fatigue detectors

20.1 Definition of technology

Driver monitoring systems can be described as follows:

"The system monitors the condition of the driver. Presently discussed parameters are tracking and warning of drowsiness, distraction and inattention"[120].

In VDI/VDE/IT, IFV Köln (2005, page 38) driver monitoring systems are also suggested to initiate emergency braking in cases where there is no driver reaction.

20.2 Accidents - Do-nothing scenario

Driver monitoring systems are aimed at reducing vehicle accidents in connection with rear end, head on and side collisions, left road accidents as well as collisions with obstacles[121]. It is e.g. specifically estimated that 30% of all truck accidents are caused by driver fatigue[122]. Another source states that 34% of fatal accidents outside urban areas are caused by driver fatigue[123].

SAFETYNET (2005, page 44) shows that approximately 60% of fatalities registered in 11 of the EU-15 countries are in rear end or head on collisions, side collisions, etc. while another 40% happen in single accidents. eSafety Forum Working Group (2002, page 26) states that fatigue may be the principal factor in 10% of all accidents.

Based on this, the potential of influencing accidents and injuries of driver monitoring systems is presented in Table 20-1. This effectively signifies that all accidents with vehicles involved are influenced by the system.

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[120] eSafety Forum Working Group (2005, page 9)

[121] VDI/VDE/IT, IFV Köln (2005, page 26)

[122] Indicated during stakeholder consultations

[123] Danmarks Transportforskning (2002, page 16-17)

Table 20-1 Share of injuries in relevant accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-15	95%	95%	95%
NMS	95%	95%	95%

20.3 Scenario for implementation

Market introduction is expected in 2009 according to VDI/VDE/IT, IFV Köln (2005). Diffusion will be based on optional or standard functions for selected models.

Based on this limited information, the estimated market penetration in this study is presented in Table 20-2. Market penetration in 2025 in the Do-nothing scenario has been estimated at 10%.

Table 20-2 Market penetration - Fatigue detectors

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	0%	10%
Do-something	0%	100%

Sensitivity analyses are made for a market deployment rate of 0% (low) and 25% (high) in 2025 for the Do-nothing scenario.

20.4 Cost assessment

No solid cost estimates are available for fatigue detectors. Hence the break-even unit costs have been estimated.

In VDI/VDE/IT, IFV Köln (2005, page 38), it is stated that investment costs are estimated to be high, while operating costs are low.

20.5 Safety impacts

The effect of driver condition monitoring, including fatigue detection, of relevant accidents (in eSafety Forum Working Group (2005) given as fatigue and 50% of left roadway accidents) is assumed to be 35%, provided that the system has been implemented in 70% of the car fleet/vehicle-kilometres. The total reductive potential for relevant accidents of the system is thus 50%. In regard to total road fatalities, the reductive potential of driver condition monitoring is expected to be approx. 3%[124].

[124] eSafety Forum Working Group (2005, page 40, 43-44)

Single accidents make up approx. 40% of total registered fatalities, as stated in the SAFETYNET (2005, page 44). 50% of these would be 20%. With a unit effect of 50%, driver monitoring systems could save 10% of total fatalities. Fatigue, etc. is also likely to influence multi-party accidents.

In this connection, a Danish study mentions that driver monitoring systems could save 4% of total accidents and 10-15% of fatalities and injuries - with a higher share of accidents involving heavy vehicles[125]. The figure of 10% is conservatively used in this study as shown in Table 20-3.

Table 20-3 Reduction in collision probability - Fatigue detectors

	Change in risk of accident
Fatalities	10% (5%-15%)
Severe injuries	10% (5%-15%)
Slight injuries	10% (5%-15%)

Note: Figures in brackets refer to min/max-values used in the sensitivity analyses

It is here assumed that driver monitoring systems have no effect on the severity of accidents if they occur.

20.6 Accidents - Do-something scenario

The effects of driver monitoring systems on the number of fatalities and injuries are summarised in Table 20-4.

It is estimated in this study that driver monitoring systems can reduce the risk of road accidents with motor vehicles in general. It is estimated that EU implementation of driver monitoring systems can save 1,962 lives in 2010 and 2,837 lives in 2020, when all vehicles have installed the required equipment. Corresponding figures for reductions in severe and slight injuries appear in the table below.

Table 20-4 Study estimate of the effect of fatigue detectors in selected years

Category	2010	2020
Fatalities	-1,962	-2,837
Severe injuries	-20,760	-33,627
Slight injuries	-204,990	-332,851

125 Danmarks Transportforskning (2002, page 16-17)

20.7 Cost-benefit assessment

The net present value of the net benefits of promoting the use of driver monitoring systems is presented in the table below. This benefit/cost-ratio can however not be estimated, due to a lack of solid cost estimates.

Table 20-5 Main results of CBA - Fatigue detectors

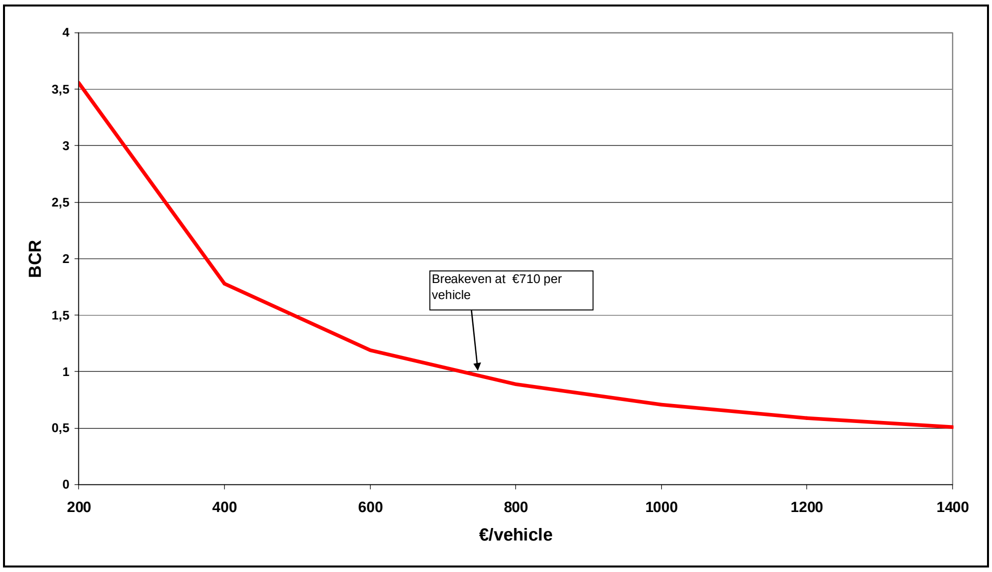
Category	Net present value in 2005, million €
Accident costs	**138,472**
Fatalities	26,996
Severe injuries	42,936
Slight injuries	68,540
Total costs	**?**
Total net present value	**?**
Benefit/cost-ratio	**?**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

As no solid cost estimates are available, the benefit/cost ratio has been estimated for a range of unit costs. The result is presented in the figure below. It can for example be seen that the benefit/cost-ratio would be 1.8 if the cost of implementing driver monitoring systems was €400 per vehicle.

The break-even costs (i.e. the costs for which the benefit/cost-ratio is 1) are estimated at €710 per vehicle. If actual costs are lower, it is cost-effective to install driver monitoring systems in all new vehicles in EU-25.

Figure 13 Benefit/cost-ratio depending on unit costs



The robustness of the results (i.e. the estimated break-even unit cost) to the values used has been evaluated. The results of selected sensitivity analyses are shown in the table below.

It can be seen that the estimated break-even unit cost are highly sensitive to the effect on collision probability.

Table 20-6 Results of sensitivity analyses - Fatigue detectors

Sensitivity analysis	Break-even unit costs (€/vehicle)
1. Low effect on collision probability (5%)	355
2. High effect on collision probability (15%)	1,065
3. Low market penetration rate in 2025 (0%)	740
4. High market penetration rate in 2025 (25%)	680
5. Low average lifetime of vehicle (12 years)	650
6. High average lifetime of vehicle (16 years)	770

21 Technology 6.3: Event or accident data recorders

21.1 Definition of technology

Accident data recorders can be defined as follows:

"The accident data recorder is an on-board event recorder. In case of accidents (or events) data on the vehicle's speed, acceleration, brake use, etc. just prior to, during and after the accident are recorded. These data can subsequently be downloaded from the accident data recorder and used to analyse how the vehicle was driven at the time of the accident. This knowledge can serve scientific, technical and legal purposes"[126].

21.2 Accidents - Do-nothing scenario

All accidents in which cars, trucks and buses are involved are relevant in relation to accident data recorders.

This corresponds to at least 95% of all registered fatalities, according to SAFETYNET (2005, page 42). This value is used in this study as shown in Table 21-1, although the share of injuries in e.g. single accidents with cyclists or cyclist/pedestrian accidents is likely to be higher than 5% in some countries.

Table 21-1 Share of injuries in relevant accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-15	95%	95%	95%
NMS	95%	95%	95%

21.3 Scenario for implementation

It has not been possible to find any references on the expected market penetration of accident data recorders. They seem to be used in some vehicle fleets in

126 Road Safety and Transport Agency (2005) and eSafety Forum Working Group (2005, page 10)

Europe. Event data recorders are used in most modern cars as serial equipment in the US[127]. In Europe some pilot projects are ongoing. Based on that, it is estimated in this study that market penetration will be 10% in 2025 in the Do-nothing scenario, as shown in Table 21-2.

Table 21-2 Market penetration - Accident data recorders

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	0%	10%
Do-something	0%	100%

Sensitivity analyses are made for a market deployment rate of 0% (low) and 25% (high) in 2025 for the Do-nothing scenario.

21.4 Cost assessment

The cost of an accident data recorder is given at approximately €100 by CARS21. In a 10 years older study, it is claimed that a unit price less than €150 is unlikely - even for very large-scale production runs[128].

Still the lower unit cost for accident data recorders is used in this study. However, sensitivity analyses are made on the basis of unit costs of €70 (low) and €150 (high)

To this should be added the cost of control of and follow-up on potential malfunction, misuse and other problems hindering the purpose of the system. This is however not taken into account here. Hence, only the unit costs are taken into account.

21.5 Safety impacts

Driver awareness of accident data recorders improves driver behaviour. Thus drivers are much more careful if their cars are equipped with accident data recorders. The behaviour change reduces the risk and severity of accidents and repair costs by up to 25% according to VERONICA (2005).

SAMOVAR (2005) calculates an effect of 41% accident reduction (given the uncertainty of results at least 13%,). Icelandic tests correspondingly show a 56% accident reduction among equipped mail vans[129].

The Danish Road Safety and Transport Agency states that field trials indicate a potential for a 20% (+/- 15%) reduction in accidents and costs[130]. Elvik (2005)

[127] VERONICA (2005)
[128] SAMOVAR (2005)
[129] The Danish Road Safety Council (2005b)
[130] Road Safety and Transport Agency (2005)

has calculated that accident data recorders can reduce fatalities by 7% in Norway and 6% in Sweden. Conversely, the eSafety Forum Working Group (2005, page 40) asserts that no significant effect on accidents is expected.

Based on the above, accident data recorders in this study are expected to have an effect as presented in Table 21-3.

Table 21-3 Reduction in collision probability - Accident data recorders

Fatalities	10% (7%-15%)
Severe injuries	10% (7%-15%)
Slight injuries	10% (7%-15%)

Note: Figures in brackets refer to min/max-values used in the sensitivity analyses

It is assumed that accident data recorders have no effect on the severity of accidents if they occur.

21.6 Accidents - Do-something scenario

The effects of accident data recorders on the number of fatalities and injuries are summarised in Table 21-4.

It is estimated that accident data recorders can reduce the potential of road accidents with motor vehicles in general. It is thus estimated in this study that EU implementation of black boxes can save 1,962 lives in 2010 and 2,837 lives in 2020, when all vehicles have installed the required equipment. Corresponding figures for reductions in severe and slight injuries appear in the table below.

Table 21-4 Study estimate of the effect of accident data recorders in selected years

Category	2010	2020
Fatalities	-1,962	-2,837
Severe injuries	-20,766	-33,627
Slight injuries	-204,990	-332,851

21.7 Cost-benefit assessment

The results of the economic cost-benefit assessment for promoting the use of accident data recorders are presented in the table below.

As can be seen, benefits are estimated to outweigh costs by a factor 7.

Table 21-5 Main results of CBA - Accident data recorders

Category	Net present value in 2005, million €
Accident costs	**138,472**
Fatalities	26,996
Severe injuries	42,936
Slight injuries	68,540
Total costs (unit related)	**-19,429**
Total net present value	**119,043**
Benefit/cost-ratio	**7.1**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

Elvik (2005) has calculated a benefit/cost-ratio of 1.1-1.5 for implementation of black boxes in Norway and Sweden.

It is difficult to assess why the benefit/cost-ratio is higher in this study compared to the results of Elvik (2005), as no specific information is available on the calculation basis for Elvik (2005). It is likely however, that costs are underestimated in this study as only unit costs are included. Besides, the expected effects of accident data recorders on relevant accidents are probably higher in this study.

The values used for key parameters in the economic cost-benefit calculations presented above are, as mentioned, uncertain.

The robustness of the results to the values used is therefore evaluated. The results of selected sensitivity analyses are shown in the table below.

For all the values used in the sensitivity analyses, benefits exceed costs. However, the estimated benefit/cost-ratio is very sensitive to the parameters used.

Table 21-6 Results of sensitivity analyses - Accident data recorders

Sensitivity analysis	BCR
1. Low unit costs (€70)	10.2
2. High unit costs (€150)	4.7
3. Low effect on collision probability (5%)	3.6
4. High effect on collision probability (15%)	10.7
5. Low market penetration rate in 2025 (0%)	7.4
6. High market penetration rate in 2025 (25%)	6.8
5. Low average lifetime of vehicle (12 years)	6.5
6. High average lifetime of vehicle (16 years)	7.7

22 Technology 6.4: Lane departure warning

22.1 Definition of technology

Lane departure warning systems can be described as follows:

"Lane departure warning (LDW) systems assist drivers in keeping their lanes by warning drivers when their car is in danger of leaving the lane unintentionally (mainly due to lack of driver attention). Current systems use either an audible beep or a "rumble strips" noise, which mimics the sound made when the tyre runs over a lane divider. Presently used in trucks - the system causes the steering wheel to vibrate and a sound comes from the appropriate side."

A supplement to the LDW system is the lane change assistant system:

"Lane change assistant (LCA) systems assist drivers intending to change lanes. The lane change assistant monitors the adjacent lanes and warns the driver if another vehicle is likely to come within colliding distance during the lane change. This occurs for example, if the other vehicle is located in the LCA-equipped vehicle's blind spot. Presently the system would warn the driver of such a problem with e.g. a red flashing side mirror. Later on a system with feedback in the steering wheel could be introduced. The lane change assistant needs predictive sensors to scan the surrounding vehicles[131]."

22.2 Accidents - Do-nothing scenario

Lane departure warning systems are targeted at reducing the risk of side collisions, head on collisions and left roadway accidents. Lane change assistance systems are limited to targeting side collisions. LDW systems target side collisions in unintended lane changes while LCA targets the intended changes[132].

In VDI/VDE/IT, IFV Köln (2005) it is stated that head on collisions and left roadway accidents make up 2.7% and 19.5% of all accidents respectively. VDI/VDE/IT, IFV Köln (2005) conservatively only include side collisions between vehicles travelling in the same direction. These are estimated to constitute 2.5% of all accidents.

[131] VDI/VDE/IT, IFV Köln (2005, page 39 & 119-124)

[132] VDI/VDE/IT, IFV Köln (2005, page 26 & 119-124)

Danish statistics show that head on collisions make up 8% of accidents (18% of fatalities), side collisions between road users travelling on same road 20% (11% of fatalities) and left roadway accidents 22% (29% of fatalities)[133]. For Germany, Bosch (2005b) states that head on collisions make up 8% of all accidents, lane departures 19%, lane changes 4% and side collisions 31%.

The corresponding figures in SAFETYNET (2005, page 44) for 11 EU15 countries are 18% of all fatalities in head on accidents, 39% in single accidents and 23% in side collisions, the latter probably including mainly collisions in junctions.

In this study it is therefore estimated that combined LDW and LDA systems can influence accidents and injuries as presented in Table 22-1.

Table 22-1 Share of injuries in relevant accidents of all road injuries

	Slight injuries	Severe injuries	Fatalities
EU-15	25%	25%	50%
NMS	25%	25%	50%

22.3 Scenario for implementation

eSafety Forum Working Group (2005, page 13-14 & 17) states that the market penetration of lane departure warning systems in the "business-as-usual" scenario is expected to be very low in 2005 (0-5%), low in 2010 (5-20%) and medium in 2020 (20-50%). In an EU support scenario, the market penetration is expected to increase to medium in 2010 and high in 2020 (50-80%).

In VDI/VDE/IT, IFV Köln (2005, page 39) it is confirmed that lane departure warning systems are currently used in lorries and are likely to be introduced in cars in 2005 as an optional comfort function. Lane change assistants are forecast to be introduced at the same time, also as an optional comfort function.

It is more pessimistically estimated that the market diffusion rate of LDW and LCA systems will be 0.6% in 2010 and 7% in 2020. Based on that, it is estimated in this study that the market penetration of LDW and LCA systems will be nil in 2006 and 10% in 2025 in the "business-as-usual" scenario.

Table 22-2 Market penetration - Lane departure warning systems

Scenario	Market deployment in 2006	Market deployment in 2025
Do-nothing	0%	10%
Do-something	0%	100%

[133] Danmarks Statistik (2003, page 17-18)

Sensitivity analyses are made for a market deployment rate of 0% (low) and 25% (high) in 2025 for the Do-nothing scenario.

As for e.g. adaptive cruise control systems, it is estimated that drivers with high vehicle-kilometres per year will choose to use LDW and LCA systems first. It is therefore assumed in VDI/VDE/IT, IFV Köln (2005) that a 3% market diffusion will lead to approximately 6% of vehicle-kilometres being influenced. A 10% market penetration will similarly affect 20% of vehicle-kilometres. This relationship is in line with the projection used in this study.

22.4 Cost assessment

According to VDI/VDE/IT, IFV Köln (2005, page 39, 119-124), investment and operating costs are medium and low for lane departure warning systems and lane change assistant systems.

Unit prices for combined LDW and LCA are given at €600 (€300 for each) in 2010 and €400 in 2020.

Based on the above costs, this analysis is based on a unit cost estimate of €400. Sensitivity analyses are made on the basis of unit costs of €300 (low) and €600 (high).

22.5 Safety impacts

The accident prevention potential of combined LDW and LCA systems, according to VDI/VDE/IT, IFV Köln (2005), is 25% for head on collisions, 25% for left roadway accidents and 60% for side collisions. Besides, an accident mitigation effect is expected by VDI/VDE/IT, IFV Köln (2005) in that the severity of accidents is shifted down a severity class - i.e. from fatality to severe injury and from severe to slight injury. No change is expected from slight to no injury. The mitigation effect is 25% for head on collisions, 15% for left roadway accidents and 10% for side collisions.

The reductive potential of lane departure warning and lane change assistant systems has also been assessed for Germany by Bosch (2005b). LDW systems are estimated to save 850 fatalities, 8,000 severe injuries and 20,000 slight injuries annually, corresponding to 12% of all fatalities, 9% of severe and 5% of slight injuries in Germany in 2002. Lane change assistants are further assessed to save 70 fatalities, 800 severe and 3,500 slight injuries.

For Spain it is estimated that LDW can save up to 10% of all rural accidents (corresponding to 5% of all rural and urban accidents)[134]. The eSafety Forum Working Group (2005, page 13 & 31-32 & 43-44) mentions the same effects on collision avoidance and mitigation as VDI/VDE/IT, IFV Köln (2005), but also notes that lane departure warning systems and similar measures can only reduce total fatal accidents by 2-4%.

[134] CARS21 (2005a, page 2)

Given that left roadway accidents constitute the largest part of the influenced accidents and that head on collisions are generally most severe, the effects used in this study (for a combined LDW and LCA system) are as shown in Table 22-3 and Table 22-4.

Table 22-3 Reduction in collision probability - Lane departure warning systems

Fatalities	25% (15%-35%)
Severe injuries	25% (15%-35%)
Slight injuries	25% (15%-35%)

Note: Figures in brackets refer to min/max-values used in the sensitivity analyses

Table 22-4 Accident severity matrix - Lane departure warning systems

Before	After			
	Fatalities	Severe injuries	Slight injuries	Avoided
Fatalities changing to…		15% (10%-20%)	0%	0%
Severe injuries changing to…	0%		15% (10%-20%)	0%
Slight injuries changing to…	0%	0%		0%

Note: Figures in brackets refer to min/max-values used in the sensitivity analyses

22.6 Accidents - Do-something scenario

The effects of lane departure warning systems on the number of fatalities and injuries are summarised in Table 22-6.

Combined lane departure warning and lane change assistant systems can reduce the risk and severity of head on and side collisions and left roadway accidents. It is thus estimated in this study that EU implementation of lane departure warning systems can save 3,941 lives in 2010 and 5,491 lives in 2020, when all vehicles have installed the required equipment. Corresponding figures for reductions in severe and slight injuries appear in the table below.

Table 22-5 Study estimate of the effect of lane departure warning systems in selected years

Category	2010	2020
Fatalities	-3,941	-5,491
Severe injuries	-19,494	-30,791
Slight injuries	-127,665	-208,554

22.7 Cost-benefit assessment

The results of the cost-benefit analysis of combined lane departure warning and lane change assistant systems are presented in Table 22-6.

As can be seen, benefits are estimated to outweigh costs by a factor 1.7.

Table 22-6 Main results of CBA - Lane departure warning systems

Category	Net present value in 2005, million €
Accident costs	**135,538**
Fatalities	53,018
Severe injuries	39,668
Slight injuries	42,851
Total costs (unit related costs)	**-77,715**
Total net present value	**57,823**
Benefit/cost-ratio	**1.7**

Note: Positive numbers reflect benefits, negative numbers reflect costs.

In comparison, VDI/VDE/IT, IFV Köln (2005, page 119-124) present results on exemplary cost-benefit calculations for combined lane departure warning and lane change assistance systems. Annual benefits and costs for EU-25 are estimated at €173 and 86 million in 2010 and 1,529 and €735 million in 2020 respectively. This gives benefit/cost-ratios of 2.0 in 2010 and 2.1 in 2020.

These ratios are in line with the results of the cost-benefit calculations in this study. It probably hides the fact that a lower uniform unit price in this study is neutralised by slightly lower effects of LDW, the expected market penetration in the "business-as-usual" scenario and the continuous change in crash and casualty rates due to improved vehicles and roads.

The robustness of the results to the values used is therefore evaluated. The results of selected sensitivity analyses are shown in the table below.

For all the values used in the sensitivity analyses, benefits exceed costs. However, the estimated benefit/cost-ratio is very sensitive to the parameters used.

Table 22-7 Results of sensitivity analyses - Lane departure warning systems

Sensitivity analysis	BCR
1. Low unit costs (€300)	2.3
2. High unit costs (€600)	1.2
3. Low effect on collision probability/accident severity (see section 22.5)	1.1
4. High effect on collision probability/accident severity (see section 22.5)	2.4
5. Low market penetration rate in 2025 (0%)	1.8
6. High market penetration rate in 2025 (25%)	1.7
5. Low average lifetime of vehicle (12 years)	1.6
6. High average lifetime of vehicle (16 years)	1.9

23 Other technologies (no cost-benefit information)

For 4 of the technologies under consideration, virtually no cost-benefit data is available. These 4 technologies are briefly discussed below.

23.1 Technology 1.6: Soft nose on trucks

Definition of technology
Soft nose on trucks can be described as follows:

Soft nose on trucks is a safety measure on trucks designed to absorb the impact energy in case of collisions between trucks and cars. In principle it functions like deformable zones in cars, soft crash barriers in front of fixed objects etc., by reducing the acute deceleration and the risk of violating the designed/intended safety zones for the road users.

Accidents - Do-nothing scenario
Soft nose on trucks is targeted at reducing the consequences of rear end, head-on and side collisions between trucks and other, typically lighter, motor vehicles. The soft nose on trucks measure does not hinder accidents. Furthermore, it only influences the severity of the accidents in which the truck front collides with another vehicle.

The available accident data from the CARE database only contains relatively simple information on the total number of fatalities involving cars and heavy vehicles respectively and on individual road user types by type of collision[135]. More specific national sources like Danmarks Statistik (2002) hold more details on the numbers of accidents between e.g. trucks and cars by type of collision, but there is no readily available information on accident numbers, fatalities or injuries in accidents involving truck fronts.

[135] SAFETYNET (2005)

23.2 Technology 4.2: Improved seats and headrests

Definition of technology
Improved seats and headrests can be described as follows:

Improved design of seats and headrests is a safety measure meant to reduce the consequences of accidents. Improvements are possible in the practical design of the seats and headrests as well as in the proper use and positioning in emergencies. Various pre-crash systems prepare the car for a crash by activating the passive safety systems like the headrests, seat position, smart restraint systems, etc.

Accidents - Do-nothing scenario
Improved design of seats and head rests is targeted at reducing the consequences of accidents, primarily whiplash injuries in rear end accidents.

The available accident data from the CARE database contains only relatively simple information on the total number of fatalities involving different types of road users and on individual road user types by type of collision[136]. National sources like Danmarks Statistik (2002) hold more details on the numbers of accidents for e.g. different road users by type of collision, but there is no readily available information on accidents resulting in whiplash injuries.

Safety impacts
CARS21 (2005a) mention that best performer headrests - compared to other "conventional" models - can reduce 40-50% of whiplash injuries.

23.3 Technology 4.3: Universal anchorage systems

Definition of technology
Universal anchorage systems for child restraint devices (ISOFIX) can be described as follows:

"ISOFIX stands for International Standards Organisation FIX. It is a standard for installing child seats into cars. When cars are manufactured, ISOFIX points are built into them. Correspondingly child seat manufacturers build ISOFIX fitting points on their child seats. This enables ISOFIX child seats to be simply plugged into the ISOFIX points in the car."[137]

ISO 13216-1 *Road vehicles - Anchorages in vehicles and attachments to anchorages for child restraint systems - Part 1: Seat bight anchorages and attachment* is the standard covering the system. The aim of this standard is to avoid the misfitting of universal child seats when installed in cars, thus reducing the risk of injury in a collision[138].

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[136] SAFETYNET (2005)
[137] CHILD CAR SEATS (2005)
[138] ISO (2005)

Accidents - Do-nothing scenario
Most child seats are currently designed to be fitted using a car's adult lap and diagonal seat belt (or sometimes just a lap belt). However, car seats, seat belts and their anchorages vary between different models of cars. At the same time they are optimised for the comfort and protection of adults. Therefore current child seats do not necessarily fit safely into all cars. An ISOFIX child seat should fit into any car by plugging it into the standard ISOFIX points[139].

The available accident data from the CARE database and other sources only contains information on the number of fatalities and injuries by age, including children of various ages. There is no information on fatalities and injuries caused by faulty or inadequate child seat instalment.

The Automobile Association states that surveys have shown that 70-80% of child seats are misfitted, with approx. 30% being seriously misfitted[140].

Scenario for implementation
The ISOFIX standard has been published, but the technical details of the standard have not yet been finalised and appurtenant regulations have apparently not been updated. However, two-point attachment ISOFIX child seats are available as standard or an option in many new cars. Presently, these are only approved for the specific car models in which they have been tested. A specific ISOFIX child seat of one manufacturer's selection has for example been approved for use in more than 80 car models. Standards for a universal, three-point ISOFIX are needed to prevent misuse of the two-point mounting and to ensure that only one test is required. Top tether straps have been used as a third anchorage in USA since 1999 and for many years in Canada and Australia[141].

Based on this, the current market penetration of child seats installed to ISOFIX standards is estimated at 5%. It is expected that the diffusion will increase markedly also in the "business-as-usual" scenario.

23.4 Technology 5.2: Brake measurement devices

Definition of technology
Brake measurement devices can be described as follows:

"Like other on-board electronic testing devices brake measurement devices are able to test a specific system in the vehicle. If the system is defective, the driver is warned or another possibility is that the vehicle is hindered in driving".

Accidents - Do-nothing scenario
Brake measurement devices are targeted at reducing accidents caused or worsened by defective brakes. Therefore all accidents with motor vehicles involved

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139 CHILD CAR SEATS (2005) and Automobile Association (2005)

140 Automobile Association (2005)

141 CHILD CAR SEATS (2005), ISO (2005) and Automobile Association (2005)

are in principle relevant for this measure. These make up approximately 95% of all reported road fatalities according to the Annual Statistical Report 2004[142].

Specifically the brake measurement device can only influence the accidents in which a defective brake is a factor. No information on this particular aspect is available in e.g. the CARE database.

In the Danish in-depth studies mentioned in chapter 16, defective brakes have not been identified as contributing to the accident risk nor the severity in any of the 111 investigated severe road accidents[143].

It is therefore likely that defective brakes only influence a very limited number of accidents, especially in EU-15. In the NMS, defective brakes may be a bigger safety problem, but no information is available on this.

Safety impacts

Is must be expected that a brake measurement device warns about or hinders the driving of a vehicle with defective brakes. Therefore all accidents with defective brakes would ideally be eliminated. Still, suddenly emerging brake problems while driving can probably not be entirely avoided. However, the device may be able to warn about the brake problem before a dangerous situation arises.

[142] SAFETYNET (2005), page 42
[143] Havarikommissionen (2002, 2003, 2005)

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