Cost-effectiveness analysis of Policy Options for the mandatory implementation of different sets of vehicle safety measures – Review of the General Safety and Pedestrian Safety Regulations

Technical Annex to GSR2 report SI2.733025

Final Report

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Annex 1 COST-EFFECTIVENESS ANALYSIS OF POLICY OPTIONS FOR THE MANDATORY IMPLEMENTATION OF DIFFERENT SETS OF VEHICLE SAFETY MEASURES – REVIEW OF THE GENERAL SAFETY AND PEDESTRIAN SAFETY REGULATIONS

Annex 1.1 Executive summary

Objective:

The objective of this in-depth cost-benefit study was to calculate concrete cost-effectiveness indicators and numbers of future casualties that could be prevented at a European level for three sets of safety measures proposed by the European Commission and considered for mandatory implementation in new vehicles starting from 2021.

Methodology and scope:

The European Commission has defined three policy options, i.e. **sets of safety measures to be implemented on a mandatory basis**, for this cost-effectiveness study to assess:

- **PO1**: State-of-the-art and widely available package of safety solutions that are not yet mandatory in EU; their fitment varies from around 5–90%
- **PO2**: As PO1 with added safety solutions that focus on vulnerable road user protection and on ensuring driver attention to the driving task
- **PO3**: As PO2 with safety solutions that are either feasible or already exist in the marketplace, but that have a low fitment rate and market uptake, that maximises overall casualty savings and can boost safety solutions' innovation

The policy options are each studied for their cost-effectiveness compared to a baseline scenario (PO0), where none of the measures are implemented on a mandatory basis, but voluntary uptake would continue.

Table 1 presents a full list of the safety measures considered for vehicle categories M1 (passenger cars), M2&M3 (buses and coaches), N1 (vans), and N2&N3 (trucks). Table 2 to Table 5 presents an overview of the sets of measures to be implemented in each policy option and the proposed introduction dates. Table 6 presents the cost estimates per vehicle category for each of the policy options assessed.

A simulation and calculation model was developed to estimate the benefits and costs associated with each policy option. The scope of the cost-effectiveness evaluation was:

- Geographic scope: EU-28
- Vehicle categories covered: M1, M2&M3, N1, N2&N3
- Evaluation period: 2021–2037
- Baseline scenario: No further policy intervention in the transport sector, but voluntary improvements and effects of already implemented policies continue. Continued dispersion of mandatory vehicle safety measures into the legacy fleet and continued voluntary uptake of the safety measures under consideration.
- Evaluated scenarios: Three sets of safety measures (PO1, PO2 and PO3) implemented on a mandatory basis
- Benefits considered: Monetary values of casualties prevented by safety measures
- Costs considered: Cost to vehicle manufacturers of fitment of safety measures to new vehicles
- Treatment of uncertainty: Interval analysis and scenario analysis
- Results: Benefit-to-cost ratios (BCRs), based on present monetary values and casualties prevented, compared to the baseline scenario over the entire evaluation period

Note that the model takes into account:

- the interactions of all measures when implemented together (to avoid double-counting of casualties prevented by different measures), and
- the effects of already existing mandatory measures (AEB-VEH and LDW for M2&M3 and N2&N3, ESC for all categories) that are still dispersing into the fleet on the European casualty target populations.

Table 1: List of safety measures considered for mandatory implementation

Measure	Description	Applicable vehicle categories			
AEB-VEH	Autonomous emergency braking for vehicles (moving and stationary targets)	M1		N1	
AEB-PCD	Autonomous emergency braking for pedestrians and cyclists	M1		N1	
ALC	Alcohol interlock installation document	M1	M2&M3	N1	N2&N3
DDR-DAD	Drowsiness and attention detection	M1	M2&M3	N1	N2&N3
DDR-ADR	Advanced distraction recognition	M1	M2&M3	N1	N2&N3
EDR	Event data recorder	M1		N1	
ESS	Emergency stop signal	M1	M2&M3	N1	N2&N3
FFW-137	Full-width frontal occupant protection (current R137 configuration with Hybrid III ATDs)	M1		N1	
FFW-THO	Full-width frontal occupant protection (introduction of THOR-M ATDs and lower appropriate injury criteria thresholds to encourage adaptive restraints)	M1		N1	
HED-MGI	Adult head-to-windscreen impact (mandatory HIC limit in headform-to-glass impact tests; no mandatory A-pillar impact)	M1		N1	
ISA-VOL	Intelligent speed assistance (voluntary type system; can be overridden by driver and switched off for the rest of journey)	M1	M2&M3	N1	N2&N3
LKA-ELK	Lane keeping assist (emergency lane keeping system that intervenes only in case of an imminent threat such as leaving the road, or leaving the lane with oncoming traffic)	M1		N1	
PSI	Pole side impact occupant protection	M1		N1	
REV	Reversing camera system	M1	M2&M3	N1	N2&N3
TPM	Tyre pressure monitoring system		M2&M3	N1	N2&N3
VIS-DET	Front and side vulnerable road user detection and warning (no auto braking)		M2&M3		N2&N3
VIS-DIV	Minimum direct vision requirement (best-in-class approach)		M2&M3		N2&N3

Table 2: Policy options for passenger cars (M1); letters indicate mandatory introduction dates[1], dash indicates measure is not included in the policy option

Measure	Baseline	PO1 (M1)	PO2 (M1)	PO3 (M1)
AEB-VEH	–	A	A	A
AEB-PCD	–	–	B	B
ALC	–	A	A	A
DDR-DAD	–	–	A	A
DDR-ADR	–	–	–	B
EDR	–	A	A	A
ESS	–	A	A	A
FFW-137	–	A	A	A
FFW-THO	–	–	A	A
HED-MGI	–	–	B	B
ISA-VOL	–	–	A	A
LKA-ELK	–	A	A	A
PSI	–	A	A	A
REV	–	–	–	A

Table 3: Policy options for buses and coaches (M2&M3); letters indicate mandatory introduction dates, dash indicates measure is not included in the policy option

Measure	Baseline	PO1 (M2&M3)	PO2 (M2&M3)	PO3 (M2&M3)
ALC	–	A	A	A
DDR-DAD	–	–	A	A
DDR-ADR	–	–	–	B
ESS	–	A	A	A
ISA-VOL	–	–	A	A
REV	–	–	–	A
TPM	–	–	–	A
VIS-DET	–	–	A	A
VIS-DIV	–	–	C	C

[1] The introduction dates for mandatory fitment are coded in the tables as follows:

- **A**: 1st September 2021 (new approved types), 1st September 2023 (new vehicles)
- **B**: 1st September 2023 (new approved types), 1st September 2025 (new vehicles)
- **C**: 1st September 2025 (new approved types), no mandatory introduction for new vehicles

Table 4: Policy options for vans (N1); letters indicate mandatory introduction dates[2], dash indicates measure is not included in the policy option

Measure	Baseline	PO1 (N1)	PO2 (N1)	PO3 (N1)
AEB-VEH	–	A	A	A
AEB-PCD	–	–	B	B
ALC	–	A	A	A
DDR-DAD	–	–	A	A
DDR-ADR	–	–	–	B
EDR	–	A	A	A
ESS	–	A	A	A
FFW-137	–	–	–	A
FFW-THO	–	–	–	A
HED-MGI	–	–	B	B
ISA-VOL	–	–	–	A
LKA-ELK	–	A	A	A
PSI	–	–	–	A
REV	–	–	–	A
TPM	–	–	–	A

Table 5: Policy options for trucks (N2&N3); letters indicate mandatory introduction dates, dash indicates measure is not included in the policy option

Measure	Baseline	PO1 (N2&N3)	PO2 (N2&N3)	PO3 (N2&N3)
ALC	–	A	A	A
DDR-DAD	–	–	A	A
DDR-ADR	–	–	–	B
ESS	–	A	A	A
ISA-VOL	–	–	A	A
REV	–	–	–	A
TPM	–	–	–	A
VIS-DET	–	–	A	A
VIS-DIV	–	–	C	C

[2] The introduction dates for mandatory fitment are coded in the tables as follows:

- **A**: 1st September 2021 (new approved types), 1st September 2023 (new vehicles)
- **B**: 1st September 2023 (new approved types), 1st September 2025 (new vehicles)
- **C**: 1st September 2025 (new approved types), no mandatory introduction for new vehicles

Table 6: Initial cost at mandatory introduction of policy options per vehicle (best estimate) inflated to year-2021 Euros

Initial cost per vehicle	PO1	PO2	PO3
Passenger cars (M1)	€201	€360	€516
Buses and coaches (M2&M3)	€6	€607	€970
Vans (N1)	€131	€206	€521
Trucks (N2&N3)	€6	€607	€1,013

Key results:

The benefit-to-cost ratios (BCRs) reported in Table 7 and Figure 1 allow a comparison of the different policy options based on the extent to which the benefits exceed (or fall short of) the costs created by a policy option over the entire evaluation period 2021–2037 compared to the baseline scenario (voluntary uptake). Values greater than 1 indicate that the benefits are greater than the costs incurred.

For passenger cars (M1) and for buses and coaches (M2&M3), the results indicate that implementation of any of the policy options considered would be cost-effective. For vans (N1), implementation of PO1 or PO2 was found to be cost-effective. For trucks (N2&N3), PO2 and PO3 exceeded the threshold to cost-effectiveness.

Table 7: Results: Benefit-to-cost ratios (BCRs) of policy options PO1, PO2 and PO3 based on present values over entire evaluation period 2021–2037 compared to the baseline scenario (best estimate)

Benefit-to-cost ratios	PO1	PO2	PO3
Passenger cars (M1)	2.95	2.14	1.39
Buses and coaches (M2&M3)	4.64	3.11	2.11
Vans (N1)	1.78	1.35	0.53
Trucks (N2&N3)	0.56	1.52	1.03

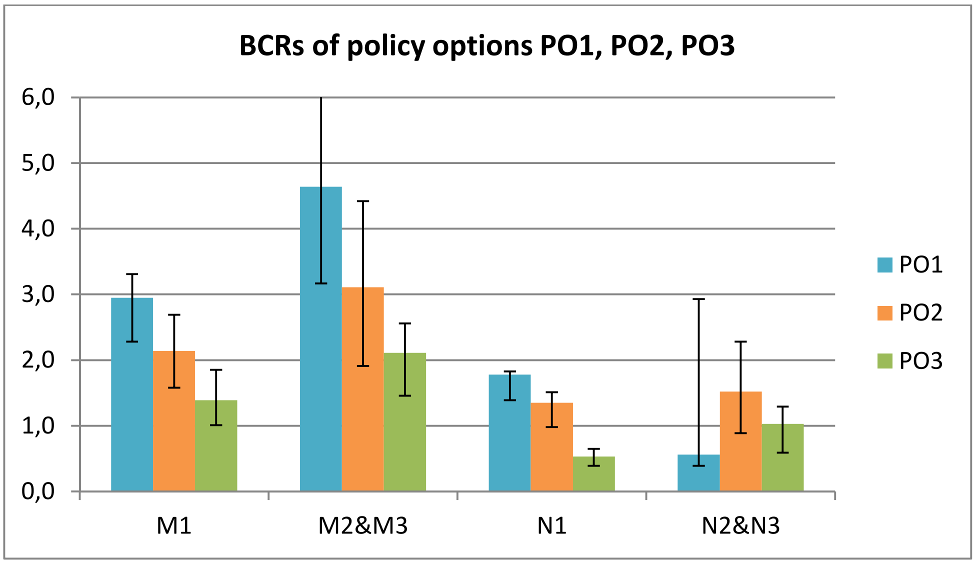

Figure 1: Results: Benefit-to-cost ratios (BCRs) of policy options PO1, PO2 and PO3 based on present values over entire evaluation period 2021–2037 compared to the baseline scenario (best estimate with indication of uncertainty ranges from scenario analysis)

The casualty prevention results reported in Table 8 and Figure 2 allow conclusions about which policy option prevents the highest number of fatalities across EU-28 when compared with the baseline scenario. To estimate the casualty prevention totals, the best estimate numbers for each year of the evaluation period 2021–2037 were summed.

It can be observed for all vehicle categories that the number of casualties prevented by implementation of PO2 or PO3 exceeds the number prevented by PO1 by a considerable margin. Between all four vehicle categories, implementation of PO2 has the potential to prevent an additional 8,312 fatalities and 51,286 serious casualties compared to PO1 across EU-28 over the period 2021–2037. PO3 exceeds the potential of PO2 by further 1,843 fatalities and 21,807 serious casualties.

Table 8: Results: Total number of fatal casualties prevented by safety measures of the respective vehicle category over the evaluation period 2021–2037 compared to the baseline scenario (best estimate)

Fatalities prevented	PO1	PO2	PO3
Passenger cars (M1)	13,785	20,081	21,337
Buses and coaches (M2&M3)	2	207	227
Vans (N1)	852	1,005	1,283
Trucks (N2&N3)	0	1,658	1,947

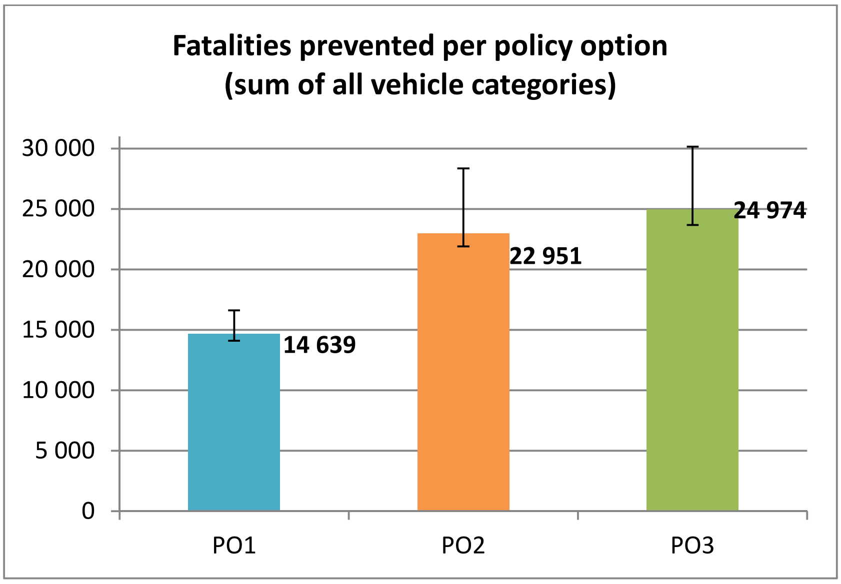

Figure 2: Results: Total sum of fatal casualties prevented by safety measures across all vehicle categories over the evaluation period 2021–2037 across EU-28 compared to the baseline scenario (best estimate with indication of uncertainty ranges from scenario analysis)

Conclusions:

From the results found in this cost-effectiveness study, it can be concluded overall that PO1 offers favourable cost-effectiveness ratios in most vehicle categories; however, these are achieved with only a small impact on both the costs and the benefits compared to the baseline scenario of continued voluntary uptake. The impacts of PO2 and PO3 are larger, with numbers of fatalities prevented exceeding those of PO1 by a considerable margin; however this is accompanied by a greater cost. Where PO2 or PO3 exceed the threshold to cost-effectiveness (BCR>1), the considerably greater number of casualties prevented compared to PO1 could be a reason to favour implementation of PO2 or PO3.

Annex 1.2 Introduction and objectives

In 2015, the European Commission published the report conducted by TRL on the *Benefit and Feasibility of a Range of new Technologies and Unregulated Measures in the Fields of Occupant Safety and Protection of Vulnerable Road Users* ('GSR1') (Hynd, et al., 2015). This Report provided initial feasibility and cost vs. benefit reviews for over 50 new safety measures that could be implemented as part of the amendment to the General Safety and Pedestrian Safety Regulations.

The follow-up report, *In Depth Cost-Effectiveness Analysis of the Identified Measures and Features regarding the Way Forward for Vehicle Safety in the EU* ('GSR2') (Seidl, et al., 2017), has been published in September 2017, and contains a thorough review and collation of the available evidence regarding effectiveness, cost, fleet penetration and target population, alongside the results of a large-scale stakeholder consultation for a shortlist of 24 safety measures. Preliminary cost-effectiveness indicators for the individual measures and additional technical considerations were reported to enable the European Commission to select the final list of proposed safety measures considered to be taken forward for mandatory implementation.

The objective of this in-depth cost-benefit study is to build upon the outcomes of the GSR1 and GSR2 projects and calculate concrete cost-effectiveness indicators and numbers of casualties prevented at a European level for three proposed sets of safety measures (policy options), taking into account:

- the interactions of all measures when implemented together (to avoid double-counting of casualties prevented by different measures),
- the baseline effects of voluntary uptake into the fleet, and
- the effects of already existing mandatory measures still dispersing into the fleet on the European casualty target populations.

Annex 1.3 Policy options and baseline scenario

The European Commission defined, based on consideration of the initial cost-benefit indicators reported in GSR2 and additional information regarding technical feasibility received in the GSR2 stakeholder consultation, the list of proposed safety measures considered for implementation (Table 9). More detail about the measures is available in the GSR2 report (Seidl, et al., 2017). Note that some measures have been split into two compared to the GSR2 report to allow more detailed modelling (DDR, FFW and VIS) and the description of some measures has evolved (HED-MGI: head-to-glass impact test; LKA-ELK: emergency lane keeping systems; REV: reversing camera).

Table 9: List of safety measures considered for mandatory implementation

Measure	Description	Applicable vehicle categories			
AEB-VEH	Autonomous emergency braking for vehicles (moving and stationary targets)	M1		N1	
AEB-PCD	Autonomous emergency braking for pedestrians and cyclists	M1		N1	
ALC	Alcohol interlock installation document	M1	M2&M3	N1	N2&N3
DDR-DAD	Drowsiness and attention detection	M1	M2&M3	N1	N2&N3
DDR-ADR	Advanced distraction recognition	M1	M2&M3	N1	N2&N3
EDR	Event data recorder	M1		N1	
ESS	Emergency stop signal	M1	M2&M3	N1	N2&N3
FFW-137	Full-width frontal occupant protection (current R137 configuration with Hybrid III ATDs)	M1		N1	
FFW-THO	Full-width frontal occupant protection (introduction of THOR-M ATDs and lower appropriate injury criteria thresholds to encourage adaptive restraints)	M1		N1	
HED-MGI	Adult head-to-windscreen impact (mandatory HIC limit in headform-to-glass impact tests; no mandatory A-pillar impact)	M1		N1	
ISA-VOL	Intelligent speed assistance (voluntary type system; can be overridden by driver and switched off for the rest of journey)	M1	M2&M3	N1	N2&N3
LKA-ELK	Lane keeping assist (emergency lane keeping system that intervenes only in case of an imminent threat such as leaving the road, or leaving the lane with oncoming traffic)	M1		N1	
PSI	Pole side impact occupant protection	M1		N1	
REV	Reversing camera system	M1	M2&M3	N1	N2&N3
TPM	Tyre pressure monitoring system		M2&M3	N1	N2&N3
VIS-DET	Front and side vulnerable road user detection and warning (no auto braking)		M2&M3		N2&N3
VIS-DIV	Minimum direct vision requirement (best-in-class approach)		M2&M3		N2&N3

This cost-effectiveness study also takes into account existing mandatory measures that are still dispersing into the fleet and thereby continue to contribute to casualty reductions; these will reduce the target populations for some of the proposed measures (see Table 10).

Table 10: List of existing mandatory safety measures which are modelled in this study

Measure	Description	Applicable vehicle categories			
AEB-VEH	Autonomous emergency braking for vehicles		M2&M3		M2&M3
ESC	Electronic stability control	M1	M2&M3	N1	M2&M3
LDW	Lane departure warning		M2&M3		M2&M3

The European Commission has defined **three policy options (POs), i.e. sets of safety measures from the above list to be implemented on a mandatory basis**, for this cost-effectiveness study to assess:

- **PO1**: State-of-the-art and widely available package of safety solutions that are not yet mandatory in EU and their fitment varies from around 5–90%
- **PO2**: As PO1 with added safety solutions that focus on vulnerable road user protection and on ensuring driver attention to the driving task
- **PO3**: As PO2 with safety solutions that are either feasible or already exist in the marketplace, but that have a low fitment rate and market uptake, that maximises overall casualty savings and can boost safety solutions' innovation

The sets of measures to be implemented in each policy option and the proposed introduction dates are shown in Table 11, Table 12, Table 13, and Table 14 for vehicle categories M1, M2&M3, N1, and N2&N3, respectively.

The introduction dates for mandatory fitment are coded in the tables as follows:

- **A**: 1st September 2021 (new approved types), 1st September 2023 (new vehicles)
- **B**: 1st September 2023 (new approved types), 1st September 2025 (new vehicles)
- **C**: 1st September 2025 (new approved types), no mandatory introduction for new vehicles

The policy options are each studied for their cost-effectiveness compared to a baseline scenario (PO0), where none of the measures are implemented on a mandatory basis, but voluntary uptake would continue. The reported cost-effectiveness results reflect a comparison between each policy option with the baseline, i.e. capture only the costs and benefits that exceed those estimated for the voluntary fitment scenario.

The evaluation period was chosen to extend to 2037 in order to capture the effects of dispersion of the measures into the vehicle fleet via fitment to new vehicles. Results are calculated for individual years, converted to present values and summed for the evaluation period extending from 2021 to 2037.

The following tables provide information on which of the safety measures are introduced under each policy option by vehicle type.

Table 11: Policy options 1, 2 and 3 for passenger cars (M1); letters indicate mandatory introduction dates (see key above), dash indicates measure is not included in the policy option

Measure	Baseline	PO1 (M1)	PO2 (M1)	PO3 (M1)
AEB-VEH	–	A	A	A
AEB-PCD	–	–	B	B
ALC	–	A	A	A
DDR-DAD	–	–	A	A
DDR-ADR	–	–	–	B
EDR	–	A	A	A
ESS	–	A	A	A
FFW-137	–	A	A	A
FFW-THO	–	–	A	A
HED-MGI	–	–	B	B
ISA-VOL	–	–	A	A
LKA-ELK	–	A	A	A
PSI	–	A	A	A
REV	–	–	–	A

Table 12: Policy options 1, 2 and 3 for buses and coaches (M2&M3); letters indicate mandatory introduction dates (see key above), dash indicates measure is not included in the policy option

Measure	Baseline	PO1 (M2&M3)	PO2 (M2&M3)	PO3 (M2&M3)
ALC	–	A	A	A
DDR-DAD	–	–	A	A
DDR-ADR	–	–	–	B
ESS	–	A	A	A
ISA-VOL	–	–	A	A
REV	–	–	–	A
TPM	–	–	–	A
VIS-DET	–	–	A	A
VIS-DIV	–	–	C	C

Table 13: Policy options 1, 2 and 3 for vans (N1); letters indicate mandatory introduction dates (see key above), dash indicates measure is not included in the policy option

Measure	Baseline	PO1 (N1)	PO2 (N1)	PO3 (N1)
AEB-VEH	–	A	A	A
AEB-PCD	–	–	B	B
ALC	–	A	A	A
DDR-DAD	–	–	A	A
DDR-ADR	–	–	–	B
EDR	–	A	A	A
ESS	–	A	A	A
FFW-137	–	–	–	A
FFW-THO	–	–	–	A
HED-MGI	–	–	B	B
ISA-VOL	–	–	–	A
LKA-ELK	–	A	A	A
PSI	–	–	–	A
REV	–	–	–	A
TPM	–	–	–	A

Table 14: Policy options 1, 2 and 3 for trucks (N2&N3); letters indicate mandatory introduction dates (see key above), dash indicates measure is not included in the policy option

Measure	Baseline	PO1 (N2&N3)	PO2 (N2&N3)	PO3 (N2&N3)
ALC	–	A	A	A
DDR-DAD	–	–	A	A
DDR-ADR	–	–	–	B
ESS	–	A	A	A
ISA-VOL	–	–	A	A
REV	–	–	–	A
TPM	–	–	–	A
VIS-DET	–	–	A	A
VIS-DIV	–	–	C	C

Some measures considered in GSR2 (Seidl, et al., 2017) will not be taken forward for mandatory implementation, following negative initial cost-benefit results or based on concerns regarding technical feasibility:

- **FSO** for M1: Small overlap frontal occupant protection, based on likely unfavourable cost-effectiveness after introduction of relevant active safety measures.
- **SFS** for M1 and N1: Side impact collision protection for far-side occupants, based on technical concerns raised by stakeholders indicating that no design solutions were proven to be effective and no suitable ATD existed for far-side impact tests.

Note that the European Commission considers removing exemptions of certain vehicle categories or weights related to the following measures:

- **F94** for M1 and N1: UN Regulation No. 94 Frontal Offset Occupant Protection – Removal of Exemptions
- **S95** for M1 and N1: UN Regulation No. 95 Side Impact Occupant Protection – Removal of Exemptions

These removals of exemptions are not covered in this cost-benefit study.

Annex 1.4 Methodology and input parameters

Annex 1.4.1 Overview: Calculation model structure

A simulation and calculation model was developed to estimate the benefits (monetary values of casualties prevented by safety measures) and costs (cost to vehicle manufacturers of fitment of safety measures to new vehicles) associated with the policy options PO1, PO2 and PO3 compared to the baseline scenario. The model was implemented in the programming language Python[3] with inputs and outputs produced in Microsoft Excel spreadsheets. Figure 3 presents a simplified visualisation of the structure and calculation steps of the model. A brief description of the steps is given in the following paragraphs and a detailed description in Annex 1.4.2 to Annex 1.4.14.

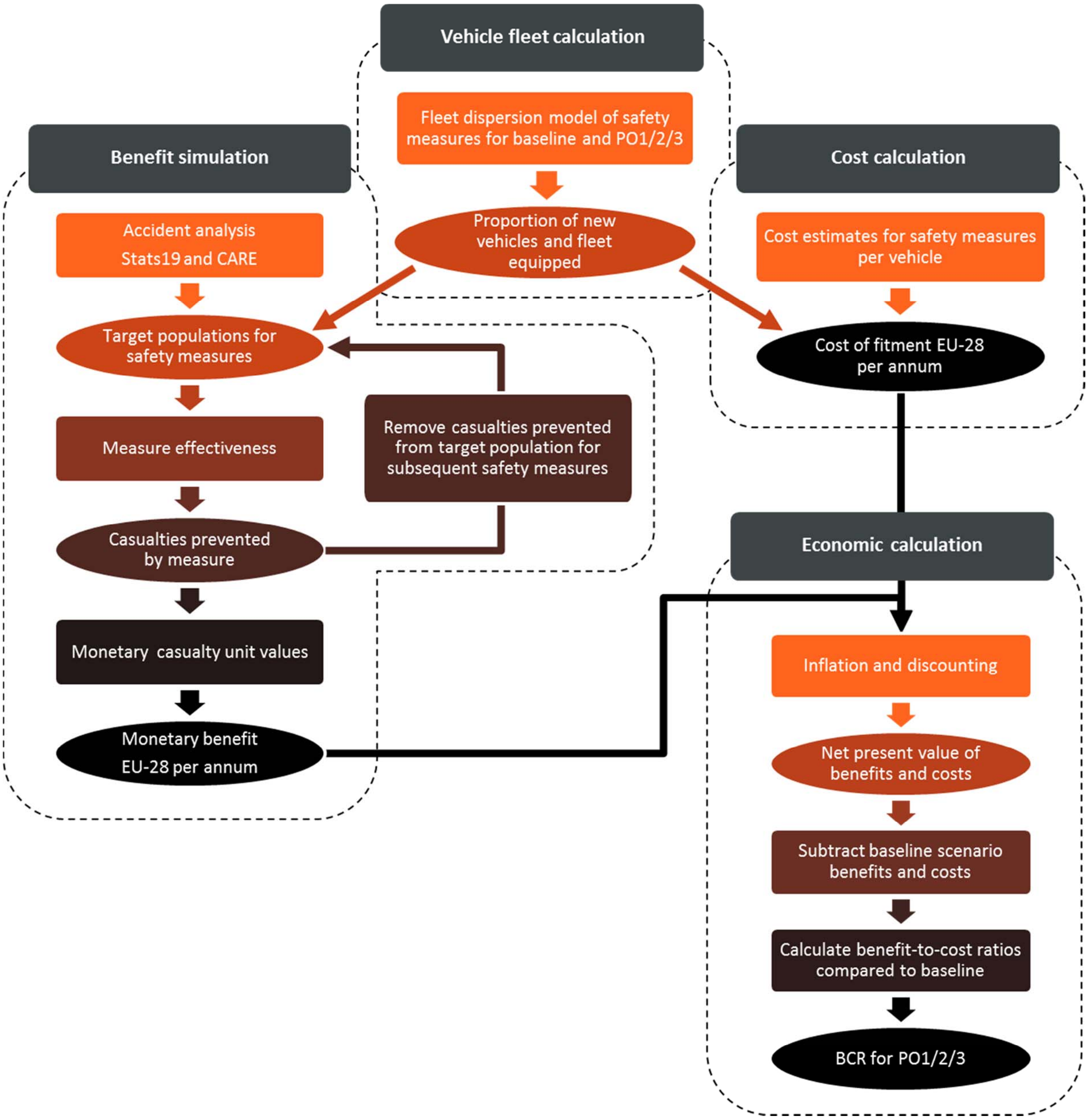

Figure 3: Flowchart of the simulation model to calculate benefit-to-cost ratios (BCRs) for policy options PO1, PO2 and PO3, respectively, compared to the baseline scenario

[3] https://www.python.org/

The vehicle fleet calculation model determines how the safety measures disperse into the fleet. The model determines the effect of mandating a measure for all new types, and two years later for all new registered vehicles, on the overall proportion of the fleet equipped. Benefits conferred by a safety measure, that is, casualties prevented, will only be realised by equipped vehicles. However, the legacy fleet will also be affected by active safety measures; for example, if a rear-end shunt is avoided by AEB-VEH, the vehicle in front, will benefit from the measure even if it is a legacy vehicle. This is taken into account in the benefit calculations.

To simulate the casualties prevented by each measure, an accident data analysis was performed based on GB national road accident data (Stats19) to determine the casualty target population for each proposed measure, i.e. the number of fatal, serious and slight casualties that could potentially be affected by a safety measure based on relevant characteristics of the collision (e.g., collision geometry or contributory factors). The target populations were scaled to EU-28 level using weighting factors, based on severity and vehicle categories involved, derived from analysis of the pan-European CARE database. The target populations found are multiplied with effectiveness values for each safety measure, i.e., a percentage value indicating what proportion of the relevant accidents will be avoided or mitigated by the measure. Mitigated casualties (fatal turned to serious casualty, or serious to slight casualty) are added to the target population of the next lower injury severity level for other measures. The casualties prevented are multiplied with monetary values for casualty prevention to calculate the monetary benefit.

An added complication that had to be addressed is the interaction of different safety measures, which address overlapping casualty groups. To give an example, there are collisions where a driver was exceeding the speed limit, left the lane and suffered a frontal impact. These collisions will be in the target populations for multiple measures: ISA, LKA-ELK and FFW-137/FFW-THO, but in reality can only be prevented once by either one of these systems. This is addressed in the model by removing casualties prevented by one measure from the subsequent target population of the other measures. The impact of highly effective existing safety measures, which have been mandatory for a few years, but are still dispersing into the vehicle fleet (ESC for all vehicle categories, and AEB-VEH and LDW for M2&M3 and N2&N3), is also modelled to reduce the remaining target populations for the proposed measures.

The cost of a policy option is calculated by multiplying per-vehicle cost estimates for each measure with the number of new vehicles of each vehicle category across EU-28 that are equipped with the measure in the given year of the analysis according to the output of the fleet calculation model. All calculations are run separately for PO1, PO2, PO3, and for the baseline scenario, which assumes that none of the proposed measures will be mandated, so all the benefits and costs in the baseline scenario result from voluntary uptake of the safety measures. The results for the baseline scenario are subtracted from the results of each policy option, in order to only capture the benefits and costs of the legislative intervention which exceed the voluntary uptake.

In the economic calculation model, the monetary values of costs and benefits are subjected to inflation and discounting to determine their present value. The present values of benefits and costs, calculated for individual years and summed over the evaluation period, are compared in order to arrive at cost-effectiveness estimates (benefit-to-cost ratio, BCR). Individual BCRs are calculated per policy option (PO1, PO2, PO3) and per vehicle category (M1, M2&M3, N1, N2&N3). A total of 12 different best estimate BCRs is reported. In addition to the calculations using the best estimate values for all input parameters, an interval and a scenario analysis is carried out to quantify the range of uncertainty around the best estimate BCR values.

The following sub-sections describe in more detail the individual aspects of the model and the input data used.

Annex 1.4.2 Evaluation period

To model the costs and benefits of the safety measures fully, it was necessary to set an evaluation window which allowed technology sufficient time to propagate through the vehicle fleet and into the collision population. This was set by considering the earliest time at which a measure could affect all new vehicles (year 2023, 2 years after introduction for new approved types); then an allowance was added for the age of the traffic population (mileage contribution to total miles driven is not constant over the vehicle age). Previous evidence, established for the car fleet in London, has demonstrated that about 88% of the traffic is 0 to 11 years old and 97% of the traffic is 0 to 14 years old. Vehicles which are 15 years old account for about only 1% of the traffic and about 2% of the collision involved cars. Therefore, 14 years was added to new vehicle implementation date to allow the full cycle of fleet benefits to be captured. This period also matches the length of time allocated for the majority of voluntary uptake measures to reach close-to-full adoption levels. As such, the evaluation period was set to extend from 2021 to 2037.

Annex 1.4.3 Casualty baseline

The EU-28 casualty baseline is an important factor for the model because it determines the size of the overall casualty target population for all safety measures over the time period assessed. The casualty baseline (policy option PO0) is also the basis against which the costs and benefits of the other policy options (PO1, PO2 and PO3) are compared.

Historically, road casualty numbers of all severity levels (fatal, serious and slight) in Europe have declined continuously over the past decades up until 2013. In the years following 2013, a slight increase or plateauing of the numbers can be observed (Figure 4).

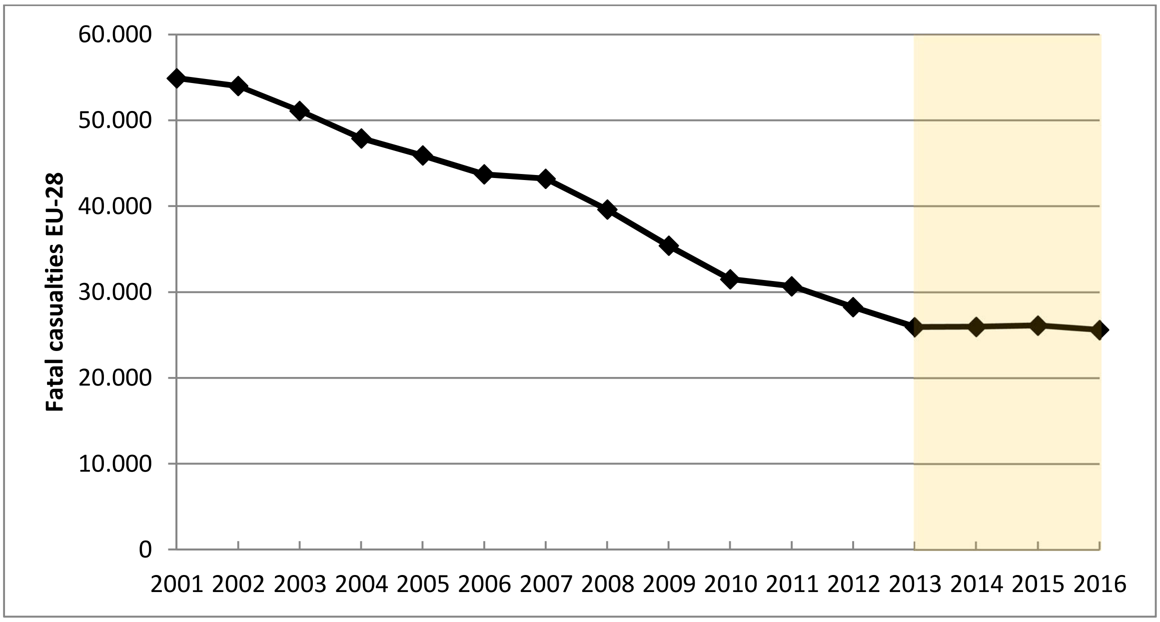

Figure 4: Historic road fatality trend EU-28[4], highlighted period 2013–2016 with plateauing trend

The reasons for the long-term decline can be attributed to advancements in vehicle safety technology (driven by regulation, consumer information programmes such as Euro

[4] https://ec.europa.eu/transport/road_safety/specialist/statistics_en

NCAP, vehicle manufacturers' research and development efforts, and independent vehicle safety research), as well as certain other major factors, including improvements to the road and cycling infrastructure, improvements in post-collision medical care, and behavioural changes of drivers due to awareness campaigns and cultural shifts (e.g. seat belt wearing rates, drink-driving behaviour, and speeding behaviour).

It was not possible within the scope of this study to attribute fractions of the overall trend to these aspects and there is no conclusive study that shows why the casualty reductions have slowed over the past five years. The European Commission, therefore, provided estimates of the continued effects in all non-vehicle-related sectors (general road casualty trend), and the vehicle-related baseline effects were calculated using the model developed for this study to arrive at the casualty baseline. The basic assumption to define the general road casualty trend and the casualty baseline was that no further policy intervention would take place in the transport sector, but voluntary improvements and effects of already implemented policies would continue.

The European Commission's best estimate provided for the general casualty trend was a constant casualty number at all severity levels from 2016 onward. This shows that the continued effects in all non-vehicle sectors are expected to offset the increase in traffic volume but not be strong enough to result in a net casualty reduction. The calculations to arrive at the casualty baseline were performed based on this general casualty trend and using input values and calculation methods as described in the subsequent sections of this report. The resulting casualty baseline reflects the effects of continued dispersion of existing mandatory vehicle safety measures with new vehicles into the legacy fleet and continued voluntary uptake of the safety measures under consideration (see Figure 5 for fatal casualties, and Annex 1.9.1 for other severity levels).

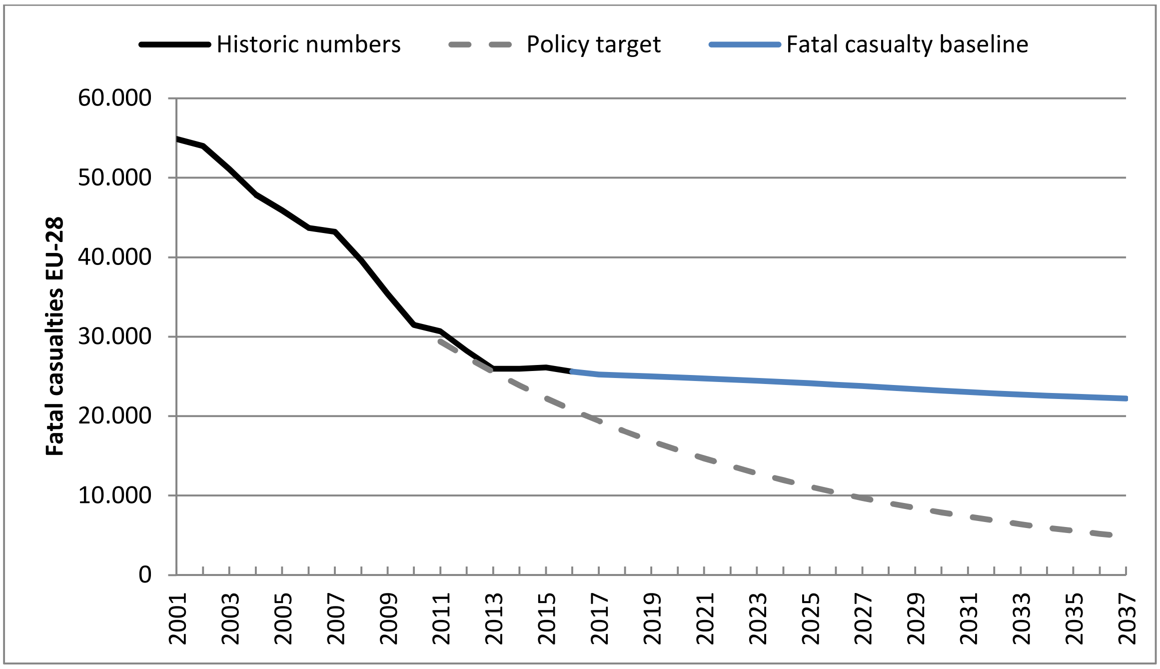

Figure 5: EU-28 fatal casualty baseline (2017–2037), historic fatality numbers (2001–2016), and indication of a potential continuation of the EU policy target (2011–2037)

Note that European member states have recently agreed on a new common definition of 'serious traffic injury' casualty, based on MAIS injury severity (MAIS3+ injuries). This is a more stringent definition than that applied in CARE (most member states report serious casualties as those where the casualty was treated as an in-patient in hospital). According to the new definition there are about 5.3 serious casualties per fatality, whereas the CARE definition captures 8.9 serious casualties per fatality. No historic numbers are available for MAIS3+ casualties across Europe and the published monetary values assigned for prevention of a serious casualty are more closely related to the CARE definition. Therefore, all calculations in this study are based on serious casualties as defined and captured in the CARE database.

In order to treat the inherent uncertainty in the forward projection of the general road casualty trend, the input numbers for fatal, serious and slight casualties were varied, along with other inputs, as part of the sensitivity analysis (see Annex 1.4.14). The European Commission's lower estimate provided was a situation where the general casualty trend (at all severity levels) would continue at the rate of fatality reduction observed within the last three years (2014–2016). This is a continuous 0.7% reduction relative to the previous year.

Refer to Annex 1.8.1 for the general casualty trend estimates and Annex 1.9.1 for the resulting casualty baseline.

Annex 1.4.4 Vehicle fleet size

Two series of data regarding the vehicle fleet were required to provide a dynamic estimate of the total benefits and costs:

1. The total fleet size each year for the period of interest; with values separated to show the different vehicle categories.
2. The number of new vehicles registered each year in Europe, again broken down to the level of vehicle categories.

The European Commission provided input numbers for both series of data, created using the PRIMES-TREMOVE transport model[5] (Table 15 and Table 16).

Table 15: EU-28 total vehicle fleet size (in thousand vehicles); Source: PRIMES-TREMOVE transport model (updated EU Reference scenario 2016)

	2010	2015	2020	2025	2030	2035	2040
Passenger cars (M1)	240,841.6	263,530.3	276,929.5	283,672.9	288,125.2	300,708.2	311,068.5
Buses and coaches (M2&M3)	818.9	905.8	980.8	1,018.3	1,039.0	1,070.8	1,107.7
Vans (N1)	27,979.6	29,645.6	30,945.4	32,230.3	33,944.6	35,871.5	37,395.6
Trucks (N2&N3)	5,876.1	7,006.8	7,842.9	8,451.2	8,888.6	9,448.6	9,965.7

[5] http://www.e3mlab.ntua.gr/e3mlab/PRIMES%2520Manual/The%2520PRIMES-TREMOVE%2520MODEL%25202013-2014.pdf

Table 16: EU-28 new vehicle registrations (in thousand vehicles, aggregated over 5 years leading up to the year referenced); Source: PRIMES-TREMOVE transport model (updated EU Reference scenario 2016)

	2010	2015	2020	2025	2030	2035	2040
Passenger cars (M1)	110,716.6	75,137.2	90,611.3	99,106.8	104,355.5	107,329.5	109,279.0
Buses and coaches (M2&M3)	381.5	309.1	319.0	343.2	364.7	357.7	369.6
Vans (N1)	10,924.9	9,810.9	10,781.0	11,931.7	12,325.1	12,638.4	13,171.2
Trucks (N2&N3)	2,482.9	2,559.3	2,471.6	2,755.6	2,943.3	3,155.9	3,161.5

The new registration data was aggregated in 5-year blocks and had to be split into individual years for this study. The middle year of each block was assigned the mean value and a slanted line was created through that value connecting each 5 year block to the next, thus avoiding to show implausible step changes every five years while obtaining the same total number.

An example of this is shown in Figure 6. In this case, the total fleet values are plotted with respect to the left axis and the new registration values with respect to the right. Refer to Annex 1.8.3 for data on other vehicle categories.

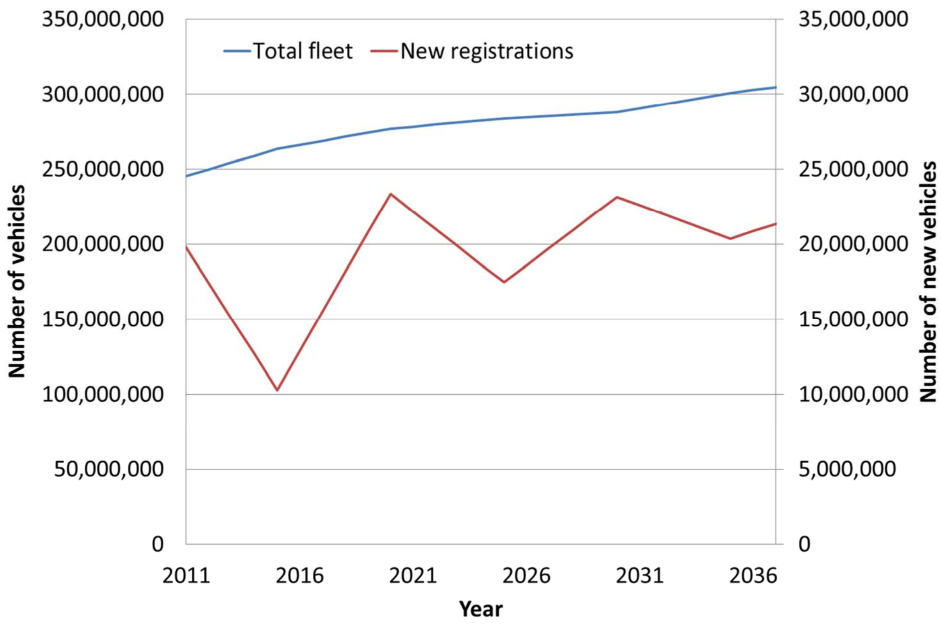

Figure 6: Passenger car (M1) fleet and new registrations 2011 to 2037

Note that the size of the fleet for the subset of M2/M3 vehicles with an extra-urban use mode (i.e. not city transport) was not available directly from the PRIMES-TREMOVE data. It was estimated using a single ratio of the M2/M3 values, which was derived from the number of vehicles in use in Europe, according to 'Eurostat' data (European Commission, 2017) and was set to be 37 % (for extra-urban type M2/M3 vehicles) for all years.

Annex 1.4.5 Fleet dispersion of safety measures

There are two aspects to the fleet fitment estimates which are vital to the process of establishing the cost-effectiveness for the measures within these policy options.

1. The voluntary uptake which defines a 'do nothing' scenario. In this case, the propagation of technology is led by the willingness of manufacturers to fit the necessary components to vehicles and the willingness of consumers to pay for them.
2. The mandatory uptake brought about by a policy intervention. In this case, all vehicles or all vehicle types will be required to meet the regulatory requirements by an implementation date. The effects of this will be superimposed on the baseline fitment rates at that moment in time.

To model the uptake of technology alongside each of the measures, it was necessary to define the uptake by new vehicles and also the penetration into the fleet due to fleet expansion and 'churn' (the rolling addition of new vehicles and scrappage of old). The numbers of vehicles being registered newly each year and the numbers in the fleet were already determined, as per the previous section. This section describes the way in which the model accounted for technology propagation on a voluntary or mandatory basis. The model accounts for the fact that some of the vehicles being scrapped in the churn process would also have the technology fitted. Otherwise, an overly optimistic estimate of technology penetration would be generated.

Voluntary fleet fitment estimates were based on evidence identified previously (Seidl, et al., 2017), comments provided by stakeholders and, in the absence of other information, opinions of an expert panel within TRL based on observations of similar technologies and expectations of pressures on the industry (for instance, whether a measure is likely to be incentivised by Euro NCAP).

The launch date for a technology was used to define the x-axis (time) start point for s-shaped curves of fitment. This relates to the first time a system was released with the characteristics likely to be required in order to meet the regulatory requirements. As a general rule, the launch date was intended to be independent of vehicle category; assuming general transfer of technologies was possible, with some exceptions. The assumed launch dates and notes about supporting observations are provided in Table 37.

The year that full voluntary implementation is achieved dictates the gradient or slope of the s-shaped curve and represents the time necessary for the measure to reach maturity in terms of full voluntary adoption into new vehicle registrations. All but three measures were predicted to have a long voluntary implementation phase, with 14 years between launch of the technology and full voluntary implementation. However, ESC was given a shorter adoption window of only 10 years to match a medium length period. For car fitment Event Data Recorders (EDR) and Full-width frontal protection for UN Regulation No. 137 with the Hybrid III dummy (FFW-137) were given an even shorter voluntary uptake period of 6 years. This was justified based on the percentage of vehicles in the fleet already expected to meet the regulatory requirements for the system, which matches the predicted final voluntary uptake levels. A medium and a long length adoption period were used for van and heavier vehicle uptake of EDRs, respectively. The full voluntary implementation years for the various measures are provided in Table 38.

The voluntary take up of technology and the implementation within the fleet was selected to be one of three possible options:

1. None = No voluntary uptake, regulatory action required to drive adoption
2. Medium = 40% voluntary propagation within the fleet without additional stimuli
3. High = 80% voluntary propagation leaving the 20% of vehicles which wouldn't be equipped without regulatory action

These values represent point estimates for the resulting final take up in the fleet. The s-shaped curve for percentage of newly registered cars equipped is modelled to form a plateau at this value. The assignments of these uptake levels to the different measures and vehicle categories are shown in Table 39 in Annex 1.8.4.

Examples of model outputs for measure uptake and fleet dispersion of AEB-PCD in cars are shown in Figure 7, Figure 8 (voluntary uptake scenario, PO0) and Figure 9, Figure 10 (mandatory uptake scenario, PO3). In the voluntary uptake scenario it can be seen that this high-uptake measure levels off at approximately 80% fleet fitment by the end of the evaluation period (Figure 8). The mandatory uptake scenario follows the voluntary uptake curve up until 2023 and elevates the new vehicle fitment rates from then onward gradually over two years to 100% (Figure 9). Even with full fitment in new vehicles, it still takes time for those vehicles to replace existing vehicles on the road, but the effect of regulation can be seen in the resulting higher fleet fitment of more than 90% by the end of the study period (Figure 10). The difference between these curves is responsible for the casualties prevented of a policy option compared to the baseline option.

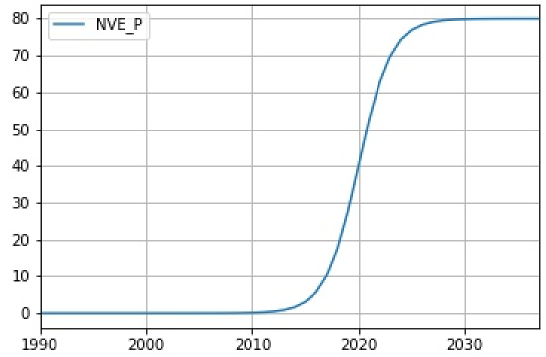

Figure 7: Percentage of newly registered cars equipped with pedestrian-capable AEB in voluntary uptake scenario

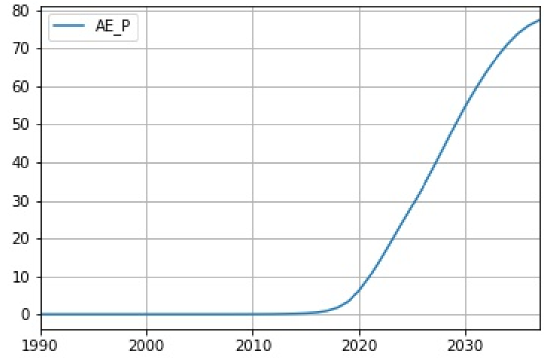

Figure 8: Percentage of all cars within the vehicle fleet equipped with pedestrian-capable AEB in voluntary uptake scenario

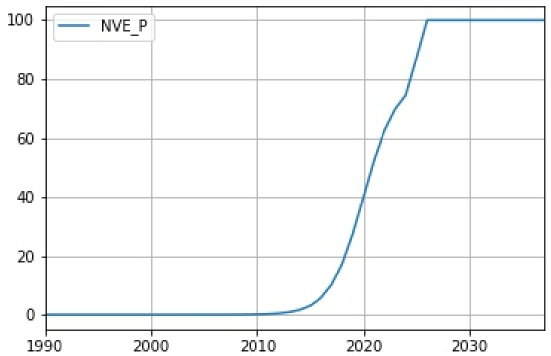

Figure 9: Percentage of newly registered cars equipped with pedestrian-capable AEB in mandatory implementation scenario (new approved types from 2023, all new cars from 2025)

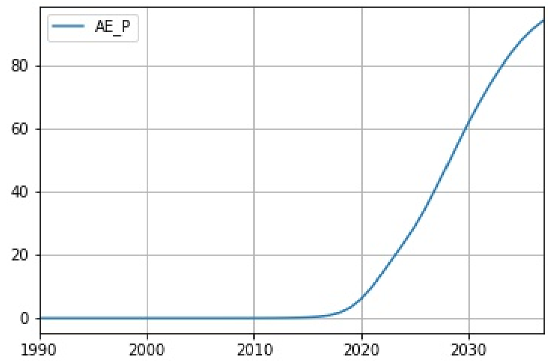

Figure 10: Percentage of all cars within the vehicle fleet equipped with pedestrian-capable AEB in mandatory implementation scenario (new approved types from 2023, all new cars from 2025)

In order to treat the inherent uncertainty in these voluntary uptake predictions, the input numbers were varied, along with other inputs, as part of the sensitivity analysis (see Annex 1.4.14). A lower estimate of the voluntary uptake was modelled to represent a scenario where voluntary uptake of the voluntary measures reaches only half the percentages quoted above.

Annex 1.4.6 Target population estimates

An accident data analysis was performed to estimate the size of the casualty target population, i.e. the number of fatal, serious and slight casualties that could potentially be affected by a safety measure based on suitable characteristics of the collision, for each of the proposed and existing safety measures.

Accident data was extracted from the Stats19 database[6] for the years 2011–2015 (last available year at the time of the study) and average numbers of this period were used to arrive at per annum estimates. Rollover collisions and collisions with more than two vehicles involved were excluded from the analysis because the police-reported data does not allow determination of which was the most severe event (injury causation) and therefore it is not clear which safety measures would apply to these collisions. Note that the calculation model corrects for the fact that the vehicle fleet was part-fitted with some of the measures under consideration at the time the accident data sample was drawn (e.g. ESC). The calculations approximate the accident data fleet fitment to be the average fleet dispersion calculated for the years 2011–2015 using the model described in Annex 1.4.5. The casualty saving effects are calculated as a reduction resulting from the relative increase in fleet fitment starting from the 2011–2015 level rather than absolute fleet fitment rate.

The data extract queries for each measure were phrased to match descriptions from the effectiveness studies used (see Annex 1.4.7). Correction factors (multipliers) were applied to the target population estimates:

- Where the Stats19 data did not offer the necessary level of detail to arrive at a suitable target population. For example, for FFW-137, the police-reported data allowed to determine the number of casualties in all frontal impacts and a correction factor smaller than one from in-depth studies was applied to represent only the fraction that was in a large overlap (full-width) frontal collision. This reduced the target population for some measures.
- Where it was known that any relevant collision circumstances or contributory factors are systematically underreported in the police-reported statistics (e.g. 'exceeding the speed limit'). This increased the target population for some measures.
- Where data from additional European countries regarding target populations for the specific measures considered was available, in order to represent the average situation in the countries available. This was, for example the case for measures HED-MGI, ISA-VOL, REV, VIS-DET and VIS-DIV. This increased or decreased the target populations for the relevant measures.

Refer to Annex 1.8.5 for an overview of target population descriptions and correction factors applied for each measure.

The target populations found were disaggregated by vehicle categories involved for (vehicle 1 and vehicle 2 or vulnerable road user), and first point of impact (e.g. N2N3 front to M1 off-side) to allow detailed modelling of the overlaps in target populations between measures (see Annex 1.4.8) and scaling to the European casualty population in the relevant vehicle combinations. This resulted in approximately 400 collision configurations and the target populations were converted into percentages of the total casualties in each of these configurations.

These target population percentages were scaled up to EU-28 to greatest level of detail possible from the data fields available within the pan-European CARE database[7]. The scaling was based on the average European casualty distribution for fatal, serious and slight casualties in the years 2011 to 2015 in collisions where the relevant vehicle categories collided (see Table 17). This means, the scaling was carried out so that it is representative of the European proportions of casualties in M1-to-M1, M1-to-N1, N1-to-

[6] Stats19 is Great Britain's database that records police reported traffic accidents that result in injury to at least one person. The database primarily records information on where the accident took place, when the accident occurred, the conditions at the time and location of the accident, details of the vehicles involved, the first point of impact, contributory factors to the accident, and information about the casualties. Approximately 50 pieces of information are collected for each accident.

[7] CARE is the community database on road accidents resulting in death or injury in the 28 European member states. https://ec.europa.eu/transport/road_safety/specialist/statistics_en#

M2M3, etc. collisions. Information regarding the first point of impact (front, off-side, near-side, rear) is not available at a pan-European level[8]. Therefore, the UK was chosen to apportion the geometric configurations within the vehicle category combinations (based on Stats19 data).

The target populations for each year were scaled proportionally to match the total casualty population for fatal, serious and slight casualties in the given year according to the general road casualty trend (see Annex 1.4.3).

Table 17: Total casualty population and collision numbers across EU-28 per annum (average of period 2011 to 2015) in the relevant vehicle category combinations. Source: CARE database

Vehicle category		Collisions	Casualties (Vehicle 1)			Casualties (Vehicle 2)		
Vehicle 1	Vehicle 2		Fatal	Serious	Slight	Fatal	Serious	Slight
M1	***none***	127,635	5,405	33,198	129,912	*n/a*	*n/a*	*n/a*
M2M3	***none***	5,313	50	818	6,625	*n/a*	*n/a*	*n/a*
N1	***none***	7,475	338	1,687	7,305	*n/a*	*n/a*	*n/a*
N2N3	***none***	4,456	222	1,209	3,578	*n/a*	*n/a*	*n/a*
PTW	***none***	52,552	1,667	16,652	38,205	*n/a*	*n/a*	*n/a*
Cyclist	***none***	25,686	335	7,662	17,848	*n/a*	*n/a*	*n/a*
Other	***none***	4,301	317	1,560	3,239	*n/a*	*n/a*	*n/a*
M1	**M1**	252,173	2,900	37,283	367,874	*n/a*	*n/a*	*n/a*
M1	**M2M3**	8,986	194	808	5,254	13	580	8,823
M1	**N1**	32,931	552	3,720	30,590	111	1,320	13,459
M1	**N2N3**	23,967	1,456	4,583	22,809	35	483	3,522
M1	**PTW**	130,523	35	731	8,797	1,939	30,768	106,274
M1	**Pedestrian**	109,876	17	206	1,980	3,600	27,549	83,758
M1	**Cyclist**	103,824	7	123	1,581	1,005	16,833	86,001
M1	**Other**	13,203	331	1,469	9,247	114	1,246	5,628
M2M3	**M2M3**	117	2	605	9,317	*n/a*	*n/a*	*n/a*
M2M3	**N1**	755	6	75	1,005	12	55	325
M2M3	**N2N3**	488	27	121	1,077	3	27	101
M2M3	**PTW**	1,410	1	11	191	52	323	1,060
M2M3	**Pedestrian**	4,260	0	48	637	184	972	2,975
M2M3	**Cyclist**	1,654	0	26	332	49	288	1,173
M2M3	**Other**	472	4	56	500	7	43	150
N1	**N1**	2,313	57	413	2,997	*n/a*	*n/a*	*n/a*
N1	**N2N3**	2,112	139	492	1,684	13	75	430
N1	**PTW**	10,374	1	33	346	271	2,435	8,230
N1	**Pedestrian**	7,685	2	9	100	463	1,832	6,102
N1	**Cyclist**	7,051	1	6	82	164	1,321	5,572
N1	**Other**	1,190	30	115	586	25	180	655

[8] First point of impact in CARE is only reported by two member states (UK and Denmark) on a regular basis, as well as sporadically by Luxembourg (2013–2015) and France (2015 only).

Vehicle category		Collisions	Casualties (Vehicle 1)			Casualties (Vehicle 2)		
Vehicle 1	Vehicle 2		Fatal	Serious	Slight	Fatal	Serious	Slight
N2N3	**N2N3**	1,688	138	629	2,019	*n/a*	*n/a*	*n/a*
N2N3	**PTW**	3,422	1	12	90	188	901	1,923
N2N3	**Pedestrian**	3,188	2	7	73	438	812	1,486
N2N3	**Cyclist**	3,790	1	4	60	218	808	2,246
N2N3	**Other**	716	15	71	277	32	121	512
PTW	**PTW**	9,683	175	2,386	8,738	*n/a*	*n/a*	*n/a*
PTW	**Pedestrian**	8,953	25	452	3,211	202	1,559	5,769
PTW	**Cyclist**	4,550	14	425	2,125	52	777	2,919
PTW	**Other**	3,477	136	893	2,214	2	128	489
Pedestrian	**Cyclist**	7,628	24	966	4,772	8	577	3,018
Pedestrian	**Other**	5,846	291	1,377	4,193	5	50	245
Cyclist	**Cyclist**	6,799	71	1,896	7,776	*n/a*	*n/a*	*n/a*
Cyclist	**Other**	2,685	78	547	1,974	1	39	170
Multi vehicle (any)		109,959	3,865	26,459	159,204	*n/a*	*n/a*	*n/a*

Annex 1.4.7 Safety measure effectiveness

The casualty target populations are multiplied with effectiveness values for each safety measure, i.e. a percentage value indicating what proportion of the relevant collisions will be avoided or mitigated by the measure.

'Avoidance' describes a situation where casualties would remain entirely uninjured after application of the effective safety measure, for example, because the collision is prevented by an active safety system. 'Mitigation' describes a situation where casualties would sustain injuries of a lower severity level (fatal turned to serious casualty, or serious to slight casualty), for example, because an effective passive safety measure prevents the most severe injuries, or an active safety measure reduces the impact speed. Measures have been assigned separate values for effectiveness of avoidance and mitigation at all injury severity levels. It should be noted that effectiveness values for avoidance and mitigation are additive in this model. 'Mitigated' casualties are subsequently added to the target population of the next lower injury severity level for other measures.

Note that casualties prevented are attributed to the vehicle category equipped with the effective safety measure, which is not always identical with the vehicle category occupied by the casualty. To give an example, if a head-on collision involving a van (N1) and a car (M1) where the van drifted out of the lane and the drivers of both vehicles were fatally injured was prevented by LKA-ELK fitted to the van, then both fatalities prevented would be counted as benefit of LKA-ELK in the N1 category.

The effectiveness best estimates were based on the values determined by (Seidl, et al., 2017) in preparation of this study (extracted from research studies and stakeholder input). Where no values could be identified during the course of this review and where no stakeholder input was provided, a road safety expert panel at TRL determined best estimates from the available evidence.

Refer to Annex 1.8.6 for the relevant effectiveness values, sources and rationale for expert panel estimates. Note that effectiveness values should always be interpreted in conjunction with the target population definition applied. Effectiveness can appear high when the target population definition is already very narrow and vice versa. For example, HED-MGI shows a high effectiveness percentage, however this applies only to the already narrow target population of '*pedestrian and cyclist casualties in impacts with the vehicle* *front who suffered serious head injuries from impact with the glazed area of the windscreen more than 10 centimetres away from the scuttle, A-pillars, and header rail*'.

For the interval and scenario analysis (see Annex 1.4.14), effectiveness values were assigned a confidence level (high or low depending on the quality of the source) and the best estimates were varied as follows in order to determine the upper and lower estimates:

- Plus/minus 10% for high confidence estimates (for example, a value of 40% would be varied ±4 percentage points, i.e. 36% to 44%)
- Plus/minus 20% for low confidence estimates.

Annex 1.4.8 Avoidance of double-counting of casualties prevented

When considering all proposed safety measures separately, the number of prevented casualties would be overestimated, because the target populations for different measures are partially overlapping, but each casualty can only be prevented once. To give an example, there will be collisions where a driver was exceeding the speed limit, left the lane and suffered a frontal impact. This collision will be in the target population for ISA, LKA-ELK and FFW-137/FFW-THO, but in reality can only be prevented once by either one of these systems. This is addressed in the model by removing casualties prevented by one measure from the subsequent target population of the other measures.

To achieve this, the proposed and existing safety measures were organised in groups that allow to take into account their interactions, to the level of detail which can realistically be expected, when all or a subset of measures are implemented. The measures are organised in 'clusters', which are based on the vehicle categories on which the measures are implemented (i.e. where the development effort and costs are accrued; and for most measures also where the benefit arises). Within each cluster, the measures are further organised in three 'layers', based on the phase in which they protect:

- Driver Assistance (permanent/ongoing collision mitigation)
- Active Safety (mitigation immediately pre-collision)
- Passive Safety (protection during collision)

The general structure for modelling the interactions between measures in this study is visualised in Figure 11. The initial target population for the calculations includes all EU-28 road casualties. Each 'layer' will prevent some of the casualties and thus reduce the target population for the next layer. The interactions/overlaps within each layer are expected to be limited because the safety systems address distinct collision causes or configurations. The reductions in target populations for subsequent layers are carried through for each of the over 400 collision configurations to realise a high level of accuracy. Note that 'mitigated' casualties (fatal turned to serious casualty, or serious to slight casualty) are added to the target population of the next lower injury severity level for other measures.

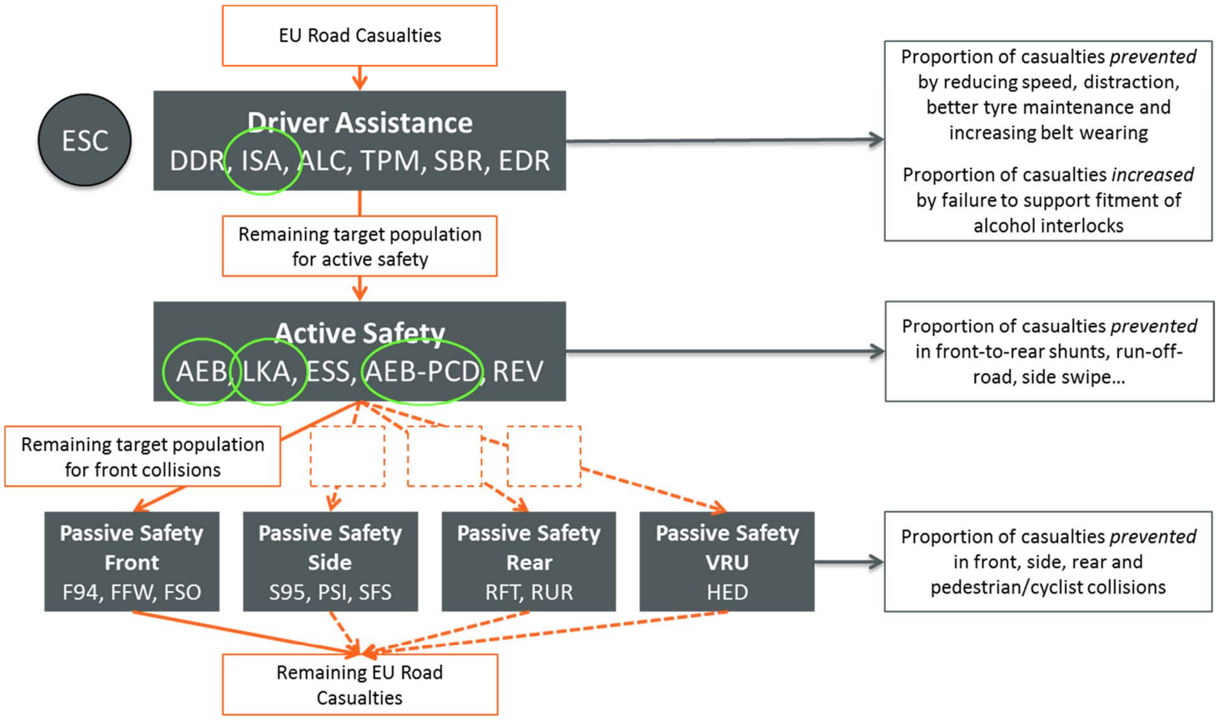

Figure 11: Modelling interactions of safety measures based on layers of protection (driver assistance, active safety, passive safety)

Refer to Annex 1.8.2 for the organisation of the proposed and existing safety measures in layers for M1, N1, M2&M3 and N2&N3 as applied in this study.

Annex 1.4.9 Monetisation of casualties prevented

The monetary values assigned for prevention of a fatal, serious and slight casualty, respectively, were based on the unit cost values suggested in the 2014 Update of the Handbook of External Costs of Transport, prepared on behalf of the European Commission, DG MOVE (Korzhenevych, et al., 2014), see Table 17[9]. The values relate to market prices in the year 2010 and were adjusted for inflation to the relevant study year, using the inflation factors described in Annex 1.4.13.

Table 18: Monetary values applied for prevented casualties, at market prices (PPP) in year 2010 euros

Casualty severity	Social unit cost
Fatal	€1,870,000
Serious	€243,100
Slight	€18,700

[9] Note: ‘Mitigated’ casualties are monetised as full prevented casualties at the higher level, but subsequently added to the remaining population of the lower level and thereby reduce the monetary benefit in the lower severity group. The benefit of a fatality turned to a serious casualty, for instance, equates to €1,626,900 based on the above values.

Note that the value of €243,100 is assigned to 'severe' injuries in the study by (Korzhenevych, et al., 2014), which appears to implicate a definition based on injury level of MAIS4+ rather than police-defined 'serious' injuries. However:

- (Korzhenevych, et al., 2014) use the terms 'serious' and 'severe' interchangeably throughout the report.
- All values in the report are updates of the values determined during the course of the HEATCO project (Bickel, et al., 2006a), which, in turn, based the serious casualty valuation on a proportion of the fatality value that was derived for the ECMT 1998 or 2001 Round Table. This Round Table saw scientific contributions from Germany, Netherlands, UK and Sweden and the definition of a 'Serious' casualty was closely related to the national police record definition, rather than a MAIS-based definition.

Therefore, the value cited above for serious casualties is most appropriately applied to the conventional reported number of serious casualties in the CARE database, rather than the new MIAS-based definition of MAIS3+ injuries.

Annex 1.4.10 Safety measure costs

Costs for the proposed safety measures were estimated on a per vehicle basis for this study. The cost values are subjected to inflation using the inflation factors described in in Annex 1.4.13 and multiplied with the number of new vehicle registrations per vehicle category in the relevant study year.

The initial cost estimates presented are to be understood to reflect the costs to the vehicle manufacturers at time of mandatory introduction, that is,

- the price a vehicle manufacturer would pay a Tier 1 supplier for fully manufactured components ('Tier 1 supplier costs') with an additional mark-up to reflect costs for acquisition, storage and installation of the components; or
- the total cost to the vehicle manufacturer, including fixed and variable cost of manufacturing and assembly, and overheads for research and development, broken down per vehicle.

Table 19 presents the initial cost estimates per vehicle for each of the policy options assessed. Refer to Annex 1.8.7 for the relevant individual cost estimates, sources and rationale for expert panel estimates.

Table 19: Initial cost at mandatory introduction of policy options per vehicle (best estimate) inflated to year-2021 Euros

Initial cost per vehicle	PO1	PO2	PO3
Passenger cars (M1)	€201	€360	€516
Buses and coaches (M2&M3)	€6	€607	€970
Vans (N1)	€131	€206	€521
Trucks (N2&N3)	€6	€607	€1,013

The cost estimates in the study reflect the assumption of high-volume manufacturing of the required components due to mandatory introduction. Based on the practice applied by agencies such as NHTSA[10] and EPA[11] in past regulatory cost-effectiveness

[10] https://www.nhtsa.gov/

evaluations[12], cost reductions through learning by doing (accumulated production volume and small redesigns that reduce costs) are applied to the initial cost estimates after first mandatory introduction of the measures (Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy; National Research Council, 2011). A two-step reduction of 20% and 10%, respectively, is applied to the initial cost-estimates in the first and second year, respectively, after introduction.

Where technology sharing of sensors between different measures was deemed possible, the relevant cost was distributed between the measures of interest. This was done for the measures AEB-VEH, AEB-PCD, ISA-VOL, and LKA-ELK, considering that these could likely be realised in a camera-based version (although radar might be necessary for more advanced systems, basic functionality could be realised using visual sensors).

The best estimates for costs were based on the values determined by (Seidl, et al., 2017) in preparation of this study (extracted from published tear-down studies and stakeholder input). Additional industry estimates from vehicle manufacturers were received and considered, where deemed appropriate, to justify upward or downward adjustments of the initial best estimates and to define the breadth of variation for the upper and lower estimate for the interval and scenario analysis. Where no values could be identified during the course of this review and where no stakeholder input was provided, a road safety expert panel at TRL determined best estimates from the available evidence. Note that most cost-estimates for N1 vehicles were derived from M1 costs, and most M2&M3 estimates from N2&N3 costs. This was necessary because the level of evidence for vans and buses and coaches was not as high as for the other vehicle categories.

Annex 1.4.11 Impact of additional safety measures on vehicle prices and sales numbers

This study makes predictions of future new vehicle sales numbers and fleet growth based on extrapolation of historic trends. It is important, in this context, to analyse whether the cost of the additional safety measures to the vehicle manufacturers would be likely to result in a substantial increase in end-user vehicle prices and thereby negatively affect new vehicle sales numbers. If this was the case, slower dispersion of the safety measures into the fleet might partially diminish the safety returns, which should be reflected in the model.

The costs calculated in this study for fitment of the proposed safety measures are to be understood to reflect the costs to the vehicle manufacturers. The full set of proposed safety measures (PO3) is estimated to create additional costs in the region of €520 per M1 and N1 vehicle, and in the region of €1,000 per M2&M3 and N2&N3 vehicle (refer to Annex 1.8.7 for details). These costs incurred by the vehicle manufacturers cannot directly be translated into a change in vehicle retail prices, because the markets for consumer, as well as commercial, vehicles are highly competitive which might not allow costs to be passed on directly; this can be observed in historic pricing data.

Up until 2011, the European Commission has published annually the 'Report on car prices within the European Union'[13]. These reports provide the most comprehensive and detailed guide to the historic development of car prices in Europe year-on-year by collating list prices for cars (i.e. before any dealership discounts) and determining the car price development in real terms, i.e. adjusted for inflation (European Commission, 2011).

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[11] https://www.epa.gov/

[12] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/deis_appx_c.pdf

[13] Available at: http://ec.europa.eu/competition/sectors/motor_vehicles/prices/report.html The car price reports were discontinued after 2011 because the Commission did not find any significant competition shortcomings in the new cars sector.

Table 20 shows the price development during the last decade of available data (2002 to 2011).

Table 20: Year-on-year change in real car prices for the last decade of available data. Source: Report on car prices within the European Union – Technical annex, Years: 2002 to 2011

Year	Year-on-year price change
2002	-0.2%
2003	-0.7%
2004	-1.9%
2005	-1.5%
2006	-1.6%
2007	-1.0%
2008	-3.2%
2009	-3.1%
2010	-0.6%
2011	-2.5%
2012 and beyond	EU car price reports discontinued; no published data

It can be seen that cars have become cheaper in real terms in every year of the last reported decade, despite this being a period in which technical development to meet new and more demanding environmental and safety standards increased, for example:

- Directive 98/69/EC and Regulation (EC) No 715/2007: Euro 4 and Euro 5 emissions standards applicable from 2005 and 2009, respectively.
- Mandatory average fleet CO_2 emissions limits: EU Regulation No 443/2009 was adopted in 2009 with mandatory compliance limits applying from 2012. The average CO_2 emissions of the new vehicle fleet sold by a manufacturer could not be reduced in a step change from one year to the next. Hence, manufacturers started around 2007, in preparation for the announced legislation, to introduce technologies that significantly reduced CO_2 emissions, in order to be able to meet the compliance limits in 2012. This can be concluded from the average rate of progress in CO_2 reduction, which accelerated considerably after 2007, compared to the long term trend before (Transport & Environment, 2011). Considerable investments in this regard therefore fall within the period of retail price decreases cited above.
- Directives 96/79/EC and 96/27/EC: Compliance with frontal and lateral crash tests for all new cars sold from October 2003.
- Regulation (EC) No 661/2009 (General Safety Regulation): Electronic stability control (ESC) applicable from 2011, mandatory gear shift indicators applicable from 2012.
- Regulation (EC) No 78/2009 (Pedestrian Safety Regulation): Emergency brake assist (EBA) applicable from 2011.

A 2011 study commissioned by the European Commission, DG Climate Action, analysed the effect of emissions and safety regulations and standards on vehicle prices (Varma, et al., 2011). The study concluded that historical vehicle price data and fitment status of certain features did not provide any definitive relationship between emissions standards and car prices. Overall, cars had become 12% to 22% cheaper (after inflation) in the study period of 2002 to 2010. The study found that, while there was certainly a cost associated for the vehicle manufacturers to comply with the environmental and safety legislation during that period, these costs were largely offset by cost reductions from economies of scale and improved productivity, because the competition in the market made it difficult to pass on cost increases to consumers. Stakeholders interviewed for the study argued that without the additional legislation, car prices would have fallen even further in that period. Nevertheless, it is evident that regulatory requirements have not stopped the trend of car retail prices decreasing, because compliance costs for emissions and safety standards are only one of the many complex factors influencing vehicle retail prices.

A report published by the European Federation for Transport and Environment (T&E) in 2011 also looked into the aspect of potential vehicle price increases specifically due to CO_2 emissions regulations and, looking back, compared the predicted influence on retail price with actual figures (Transport & Environment, 2011). The authors came to a similar conclusion as (Varma, et al., 2011): That car retail prices were influenced by a complex set of factors, with compliance costs being only one of them, and that concerns over cars becoming unaffordable due to CO_2 emissions regulations had been unfounded.

The past experience with CO_2 emissions legislation also allows comparing predicted additional costs with predicted and actual retail price increases: In a 2006 study prepared for the European Commission, the researchers from TNO had estimated the future costs to manufacturers of reaching the required average CO_2 targets to be an additional €832 per car in 2008, compared to a year-2002 baseline (Smokers, Vermeulen, van Mieghem, & Gense, 2006). This was expected by the authors to translate to an additional retail price of €1,200 per car in 2008, again compared to 2002. In reality however, cars have become approximately 10% cheaper (after inflation) between 2002 and 2008 (see Table 20), which equates to a price reduction of €2,000 for a €20,000 model. These figures show that, bearing in mind the scale of investment required to meet emissions requirements, coupled with the costs of the other aspects cited above, the costs to vehicle manufactures related to the fitment of new safety measures in the present study are not considered to be orders of magnitude different in scale than past predictions which did not translate to retail price increases.

Interpreting the general price trend and the conclusions from the cited studies on compliance costs, it can be concluded that vehicle manufacturers in the past have found strategies and practices to balance production costs and regulatory compliance. This has been, for example, via increases in production efficiency, or accepted temporarily reduced profit margins to at least partially offset any cost increase, because the competitive nature of the vehicle market did not allow substantial retail price increases. Past evidence therefore suggests that requiring additional equipment for CO_2 emission standards, which was estimated at a cost higher than the present estimates for the full set of proposed safety measures, did not cause an increase in retail prices. Substantial increases in vehicle prices due to the additional safety measures in the medium and long term are therefore not expected and consequently no extraordinary impact on vehicle sales numbers was modelled for the cost-benefit analysis.

Annex 1.4.12 Discounting of costs and benefits

A discounting rate is applied in the economic analysis for this study to relate the benefits and costs occurring in future years to the present. A 'social discount rate' *r* is applied to reflect the fact that benefits and costs further ahead in the future are valued lower than present benefits and costs.

The present value *PV* of costs *C* in the years t=0 to the end of the appraisal period t=T is calculated as (Bickel, et al., 2006a):

$$PV = \sum_{t=0}^{T} C_t \times \frac{1}{(1+r)^t}$$

The present value of benefits is calculated in the same way.

Recommended social discount rates for EU transport projects in relevant guidelines range between 3% (recommended in the HEATCO project as lower bound for sensitivity analysis, (Bickel, et al., 2006b)) and up to 5.5% (recommended by DG Regional Policy for investments in Cohesion countries, (European Commission, DG Regional Policy, 2008)).

For the current CBA an average rate between these recommendations, i.e.

$$r = 4.25\%,$$

was chosen for the central estimate calculations. The interval analysis range was set as $r_{low} = 3.0\%$ to $r_{high} = 5.5\%$. A constant rate *r* was applied over time for the entire analysis period, which is in line with the HEATCO recommendations, which only call for a declining discount system if intergenerational impacts are concerned in very long appraisal periods (Bickel, et al., 2006b).

Annex 1.4.13 Inflation of monetary values

An inflation rate is applied to all monetary values in this study to adjust cost and benefit estimates from the past to current values and to factor in future devaluation. The inflation rate used is the year-on-year percentage change of the Harmonised Index of Consumer Prices published by Eurostat. For the past, historic data from Eurostat was used; for the future forecasts by the European Central Bank (Table 21).

Table 21: Year-on-year inflation rates applied in the study

Year	Inflation rate	Type	Source
2008	3.7%	actual	(Eurostat, 2017)
2009	1.0%	actual	(Eurostat, 2017)
2010	2.1%	actual	(Eurostat, 2017)
2011	3.1%	actual	(Eurostat, 2017)
2012	2.6%	actual	(Eurostat, 2017)
2013	1.5%	actual	(Eurostat, 2017)
2014	0.5%	actual	(Eurostat, 2017)
2015	0.0%	actual	(Eurostat, 2017)
2016	0.3%	actual	(Eurostat, 2017)
2017	1.5%	forecast	(European Central Bank, 2017a)
2018	1.4%	forecast	(European Central Bank, 2017a)
2019	1.6%	forecast	(European Central Bank, 2017a)
2020	1.8%	forecast	(European Central Bank, 2017a)
2021	1.8%	forecast	(European Central Bank, 2017a)
2022	1.8%	forecast	(European Central Bank, 2017a)
2023 and beyond	2.0%	forecast	(European Central Bank, 2017b)

Annex 1.4.14 Sensitivity analysis

To quantify the range uncertainty around the best estimate BCR values, two sensitivity analysis techniques common in cost-benefit evaluations were applied (Bickel, et al., 2006a):

- Interval analysis, and
- Scenario analysis.

Input parameters which have a strong influence on results and a relatively high associated uncertainty were identified as:

- Measure effectiveness (directly influencing the number of casualties saved),
- Measure cost (directly influencing the fitment cost),
- Discounting rate (influencing the weight of short-term and long-term effects),
- General road casualty trend (influencing the size of the target population for the safety measures), and
- Voluntary measure uptake (influencing the baseline to which the other policy options are compared).

The best estimate and upper/lower estimate values for these parameters were chosen as described in the previous sub-sections or in the appendices. Refer to Table 22 for an overview of the combination of input parameters used for each analysis. The other input parameters remained unchanged.

Table 22: Varied input parameter values for interval and scenario analysis

	Interval analysis (absolute lower BCR)	Scenario analysis (expected lower BCR)	Best estimate analysis	Scenario analysis (expected upper BCR)	Interval analysis (absolute upper BCR)
Measure effectiveness	Lower estimate	Upper estimate	Best estimate	Lower estimate	Upper estimate
Measure cost	Upper estimate	Upper estimate	Best estimate	Lower estimate	Lower estimate
Discounting rate	Upper estimate	Best estimate	Best estimate	Best estimate	Lower estimate
General road casualty trend	Lower estimate	Lower estimate	Best estimate	Best estimate	Best estimate
Voluntary measure uptake	Best estimate	Best estimate	Best estimate	Lower estimate	Lower estimate

The interval analysis was carried out to determine the absolute upper and lower bound of the BCR. The parameters mentioned above were varied in a direction that represents an absolute optimistic assumption (absolute upper BCR) and an absolute pessimistic assumption (absolute lower BCR). These are the outer bounds of variation that could be conceivable according to the model employed under extreme circumstances; however, these bounds would only be met in the improbable case that future reality diverges from the estimated input values in the same direction for each of the safety measures.

The scenario analysis was carried out to reflect the bounds of variation that could be expected in a scenario where the input value estimates applied had a tendency to systematically underestimate both effectiveness and costs (expected upper BCR), or to systematically overestimate both (expected lower BCR), and where the voluntary measure uptake (expected upper BCR) or the general road casualty trend (expected lower BCR) would be lower than expected.

The resulting absolute and expected upper/lower BCR results are reported alongside each best estimate BCR.

Annex 1.4.15 Data sources and stakeholder validation

In preparation of this cost-effectiveness study, the European Commission tasked TRL to collate the most up-to-date, high quality data available on effectiveness, cost, fleet penetration and target population of the safety measures. TRL selected the best sources for these parameters from the body of published evidence based on quality of research, quality of data, timeliness and relevance and extract suggested input values.

This was followed by a wide stakeholder consultation where stakeholders were asked to provide values for parameters (if no published evidence was available), to validate or contest TRL's preliminary suggested values with additional evidence, and to comment on the proposed method for avoidance of double-counting of casualties prevented (three layers of protection). 72 representatives from 54 organisations (including vehicle manufacturers, Tier 1 suppliers, government organisations, non-government organisations in the area of road safety and environment, consumer organisations, academic and vehicle safety research and development organisations and consultancies) attended the two-day stakeholder meeting. In addition, 32 organisations provided written feedback.

All inputs, provided in writing or during the two-day face-to-face meeting, were documented and, where appropriate, used to update and refine the input values proposed for this cost-effectiveness study. The input values found in this process were collated in the report *In Depth Cost-Effectiveness Analysis of the Identified Measures and Features regarding the Way Forward for Vehicle Safety in the EU* ('GSR2') (Seidl, et al., 2017) and are referenced throughout Annex 1.8.1 to Annex 1.8.7 of this report. Where additional sources or expert panel assessments were required, this is explained in Annex 1.4.1 to Annex 1.4.15 and referenced alongside the numbers.

Annex 1.4.16 Limitations

In general, the model has used various input values (e.g. inflation rate, number of new registrations, measure effectiveness, etc.) to predict the effects of different policy options. Predictions of the future are by definition inherently subject to a degree of uncertainty. This study has used input values based on historical trends; the interval and scenario analysis provides assessment of the effect that deviations from the expected trend may have on the outcome, but cannot completely account for very extreme changes in circumstances. The following important limitations of the simulation model employed and the input value estimates should be taken into account when interpreting the results.

The accident data analysis to determine the target populations for the safety measures was based on GB national data rather than pan-European data. The EU-wide accident data available from CARE did not offer the level of detail necessary to perform this analysis because it does not contain contributory factors of collisions or data on the first point of impact on vehicles. Where data from additional European countries regarding target populations for the specific measures considered was available, this was incorporated by applying target population correction factors to represent the average situation in the countries available. This was the case for measures HED-MGI, ISA-VOL, REV, VIS-DET and VIS-DIV. To arrive at estimates valid for the European Union, the target population percentages found were scaled up to EU-28 to greatest level of detail possible from the data fields available within the CARE. The scaling was based on the average European casualty distribution for fatal, serious and slight casualties in collisions where the relevant vehicle categories collided. This means, the scaling was carried out so that it is representative of the European proportions of casualties in M1-to-M1, M1-to-N1, N1-to-M2M3, etc. collisions.

The effectiveness and cost estimates used are subject to a degree of uncertainty. The level of uncertainty varies between safety measures, with the level of evidence available for each measure from research. The level of evidence was good for some well-established measures (e.g. AEB and AEB-PCD) and less robust for some other measures (e.g. DDR-DAD and DDR-ADR). Both, effectiveness and cost estimates were established using a thorough review process during the GSR2 project which involved large-scale stakeholder consultations and are therefore considered to represent the highest level of evidence that could be acquired. To treat the remaining uncertainty in these values, upper and lower estimates were employed for the interval and the scenario analysis.

The casualty simulations and cost calculations are based on a continuation of existing trends into the future (with expected variability in these trends captured in the scenario analysis). This approach cannot capture any potential disruptions that might occur in the mobility market in the future, such as autonomous driving radically changing the collision landscape, mobility as a service reducing private car ownership and potentially increasing overall miles driven, or a severe economic crisis reducing new vehicle uptake. Disruptions are highly uncertain and impossible to predict as to when, if, and to what extent they will happen and their impact could not be captured in the models other than in a highly speculative way, which would undermine the evidence-base for the analysis.

The results of the cost-benefit analysis should be interpreted with this context in mind and understood as an evidence-based, detailed prediction of the cost-effectiveness of the policy options if historic trends continue within a range of expected uncertainty.

Annex 1.5 Results

Annex 1.5.1 Cost-effectiveness of policy options

The main results of the cost-effectiveness evaluation are presented in the following tables and figures, separated by vehicle category cluster (M1, M2&M3, N1 and N2&N3, respectively). Further results for indvidual years of the evaluation period and ranges of uncertainty are given in Annex 1.9.2 and Annex 1.9.3, respectively.

The benefit-to-cost ratios (BCRs) reported allow a comparison of the different policy options based on the extent to which the benefits exceed (or fall short of) the costs created by a policy option over the entire evaluation period 2021–2037, compared to the baseline scenario (voluntary uptake). Values greater than 1 indicate that the benefits are greater than the costs incurred.

For passenger cars (M1), the results indicate that implementation of any of the policy options would be cost-effective, according to the best-estimate calculations and also within the expected lower and upper estimate band found in the scenario analysis. PO1 resulted in the highest BCR for passenger cars.

For buses and coaches (M2&M3), all policy options were found to be cost-effective according to best estimate calculations and also within the expected lower and upper estimate band. PO1 has the highest BCR; however note that this ratio is achieved, by this policy option consisting of only two measures, which has minimal impact on both costs and benefits as can be seen from the casualty prevention results (Annex 1.5.2).

For vans (N1), implementation of PO1 and PO2 were found to be cost-effective according to the best-estimate calculations. The band of expected uncertainty for PO2 just spans the threshold of cost-effectiveness. PO3 was found to be less cost-beneficial and did not exceed the threshold of cost-effectiveness.

For trucks (N2&N3), PO2 and PO3 exceeded the threshold of cost-effectiveness, according to best estimate calculations. PO2 presented the most favourable BCR with the expected lower BCR value falling short of cost-effectiveness by a small margin. For PO3, the expected lower and upper estimate band straddled the threshold of cost-effectiveness.

When interpreting the results it should also be considered that only safety benefits of the assessed measures have been considered in this study. Non-quantified benefits, such as, productivity gains due to the reduction in traffic congestion associated with road traffic collisions or reduced CO_2 emissions caused by TPM, will contribute to a greater benefit of the policy options.

Passenger cars (M1):

Table 23: Passenger cars (M1): Benefit-to-cost ratios (BCRs) of policy options PO1, PO2 and PO3 based on present values over entire evaluation period 2021–2037 compared to the baseline scenario; uncertainty ranges from scenario and interval analysis

Passenger cars (M1)	PO1		PO2		PO3	
BCR (best estimate)	**2.95**		**2.14**		**1.39**	
BCR (expected lower/upper)	2.28	3.31	1.58	2.69	1.01	1.85
BCR (absolute lower/upper)	1.83	4.14	1.31	3.30	0.84	2.27

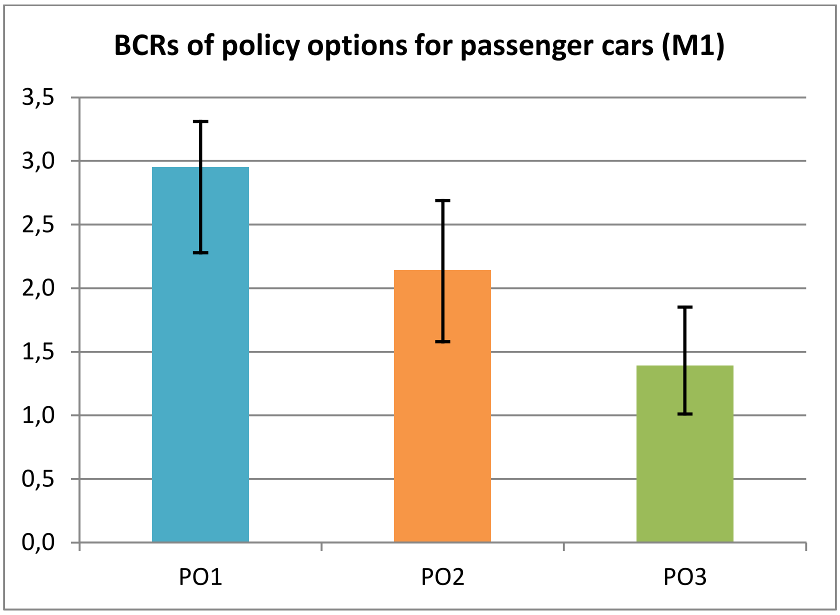

Figure 12: Passenger cars (M1): Comparison of best estimate benefit-to-cost ratios (BCRs) of policy options PO1, PO2 and PO3, with indication of uncertainty ranges from scenario analysis

Table 24: Passenger cars (M1): Present monetary value of benefits and costs of policy options PO1, PO2 and PO3 over entire evaluation period 2021–2037 compared to the baseline scenario (best estimate)

Passenger cars (M1)	PO1	PO2	PO3
Present value benefit	€37.5 bn	€57.4 bn	€64.1 bn
Present value cost	€12.7 bn	€26.9 bn	€46.0 bn

Buses and coaches (M2&M3):

Table 25: Buses and coaches (M2&M3): Benefit-to-cost ratios (BCRs) of policy options PO1, PO2 and PO3 based on present values over entire evaluation period 2021–2037 compared to the baseline scenario; uncertainty ranges from scenario and interval analysis

Buses and coaches (M2&M3)	PO1		PO2		PO3	
BCR (best estimate)	**4.64**		**3.11**		**2.11**	
BCR (expected lower/upper)	3.17	14.32	1.91	4.42	1.46	2.56
BCR (absolute lower/upper)	2.11	21.72	1.37	6.26	1.03	3.65

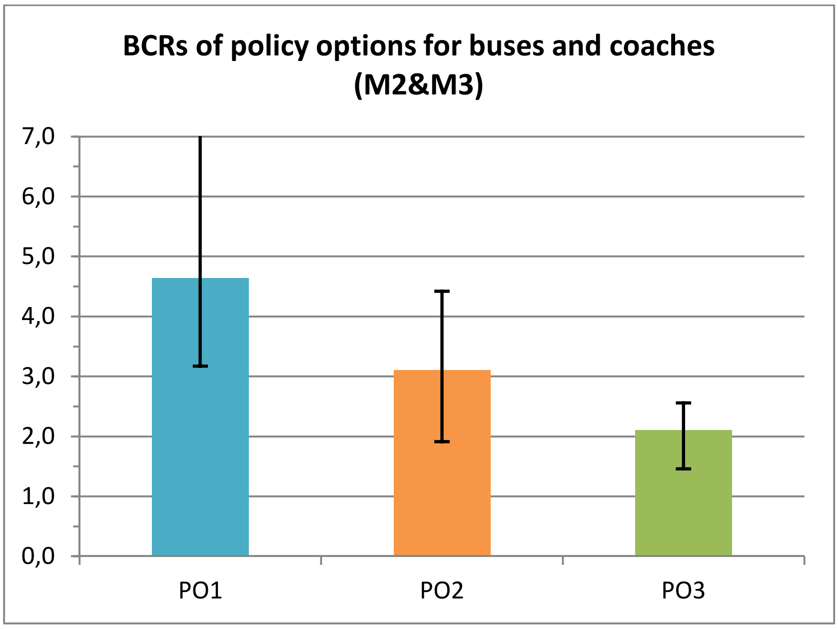

Figure 13: Buses and coaches (M2&M3): Comparison of best estimate benefit-to-cost ratios (BCRs) of policy options PO1, PO2 and PO3, with indication of uncertainty ranges from scenario analysis

Table 26: Buses and coaches (M2&M3): Present monetary value of benefits and costs of policy options PO1, PO2 and PO3 over entire evaluation period 2021–2037 compared to the baseline scenario (best estimate)

Buses and coaches (M2&M3)	PO1	PO2	PO3
Present value benefit	€11.2 mn	€813.7 mn	€937.0 mn
Present value cost	€2.4 mn	€262.0 mn	€444.5 mn

Vans (N1):

Table 27: Vans (N1): Benefit-to-cost ratios (BCRs) of policy options PO1, PO2 and PO3 based on present values over entire evaluation period 2021–2037 compared to the baseline scenario; uncertainty ranges from scenario and interval analysis

Vans (N1)	PO1		PO2		PO3	
BCR (best estimate)	**1.78**		**1.35**		**0.53**	
BCR (expected lower/upper)	1.39	1.83	0.98	1.51	0.39	0.65
BCR (absolute lower/upper)	1.09	2.33	0.79	1.88	0.31	0.81

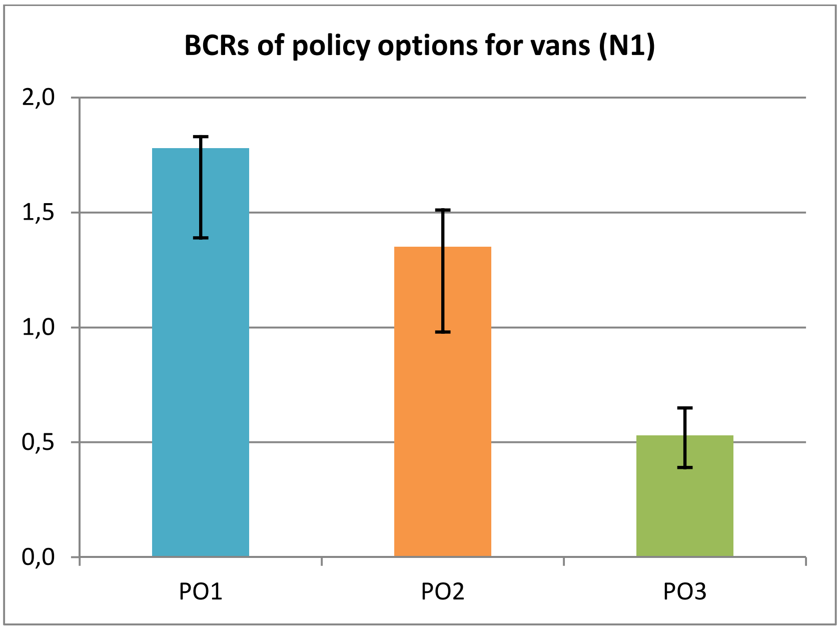

Figure 14: Vans (N1): Comparison of best estimate benefit-to-cost ratios (BCRs) of policy options PO1, PO2 and PO3, with indication of uncertainty ranges from scenario analysis

Table 28: Vans (N1): Present monetary value of benefits and costs of policy options PO1, PO2 and PO3 over entire evaluation period 2021–2037 compared to the baseline scenario (best estimate)

Vans (N1)	PO1	PO2	PO3
Present value benefit	€2.3 bn	€2.8 bn	€3.7 bn
Present value cost	€1.3 bn	€2.0 bn	€6.9 bn

Trucks (N2&N3):

Table 29: Trucks (N2&N3): Benefit-to-cost ratios (BCRs) of policy options PO1, PO2 and PO3 based on present values over entire evaluation period 2021–2037 compared to the baseline scenario; uncertainty ranges from scenario and interval analysis

Trucks (N2&N3)	PO1		PO2		PO3	
BCR (best estimate)	**0.56**		**1.52**		**1.03**	
BCR (expected lower/upper)	0.39	2.93	0.89	2.28	0.59	1.29
BCR (absolute lower/upper)	0.25	4.49	0.73	2.81	0.47	1.63

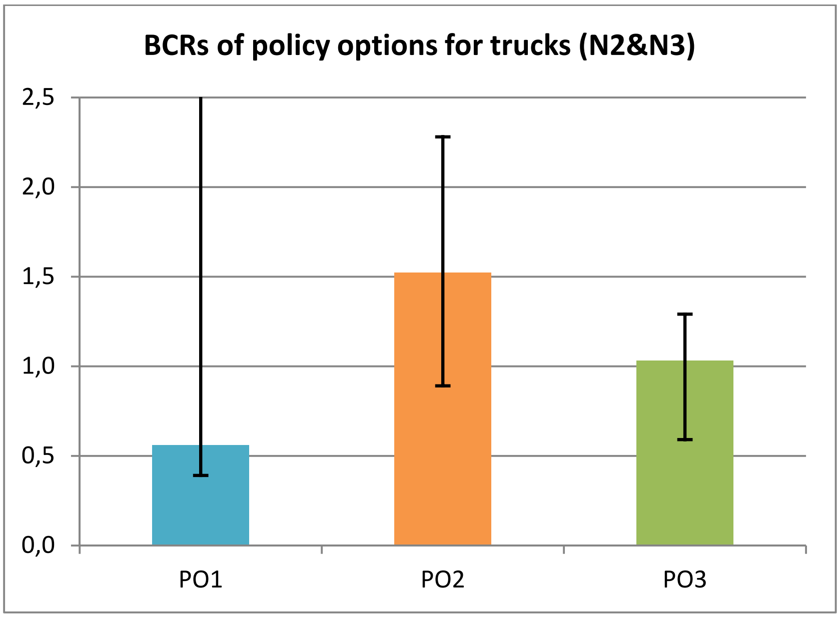

Figure 15: Trucks (N2&N3): Comparison of best estimate benefit-to-cost ratios (BCRs) of policy options PO1, PO2 and PO3, with indication of uncertainty ranges from scenario analysis

Table 30: Trucks (N2&N3): Present monetary value of benefits and costs of policy options PO1, PO2 and PO3 over entire evaluation period 2021–2037 compared to the baseline scenario (best estimate)

Trucks (N2&N3)	PO1	PO2	PO3
Present value benefit	€ 0.01 bn	€3.4 bn	€4.1 bn
Present value cost	€ 0.02 bn	€2.2 bn	€4.0 bn

Annex 1.5.2 Casualties prevented by policy options

The main results of the casualty prevention simulations are presented in the following tables and figures separated by vehicle category cluster (M1, M2&M3, N1 and N2&N3, respectively). Further results for indvidual years of the evaluation period are given in Annex 1.9.3.

Comparison of the results allows conclusions about which policy option prevents the highest number of casualties[14,15] across EU-28 when compared with the baseline scenario. To estimate the casualty prevention totals, the best estimate numbers of all years of the evaluation period 2021–2037 are summed.

It can be observed for all vehicle categories that the number of casualties prevented by implementation of PO2 or PO3 exceeds the number prevented by PO1 by a considerable margin. Between all four vehicle categories, implementation of PO2 has the potential to prevent an additional 8,312 fatalities and 51,286 serious casualties compared to PO1 across EU-28 over the period 2021–2037. PO3 exceeds the potential of PO2 by further 1,843 fatalities and 21,807 serious casualties.

[14] When interpreting the results, it should be noted that casualties prevented were attributed to the vehicle category equipped with the effective safety measure, which is not always identical with the vehicle category occupied by the casualty. To give an example, if a head-on collision involving a van (N1) and a car (M1) where the van drifted out of the lane and the drivers of both vehicles were fatally injured was prevented by LKA-ELK fitted to the van, then both fatalities prevented would be counted as benefit of LKA-ELK in the N1 category.

[15] It should further be noted that 'mitigated' casualties were added to the remaining casualties at the next lower injury severity level.

All vehicle categories (total sum):

Table 31: Total sum of casualties prevented by safety measures across all vehicle categories over the evaluation period 2021–2037 across EU-28 compared to the baseline scenario (best estimate)

All categories	PO1	PO2	PO3
Fatalities prevented	14,639	22,951	24,794
Serious casualties prevented	67,647	118,933	140,740
Slight casualties prevented	288,293	421,562	515,681

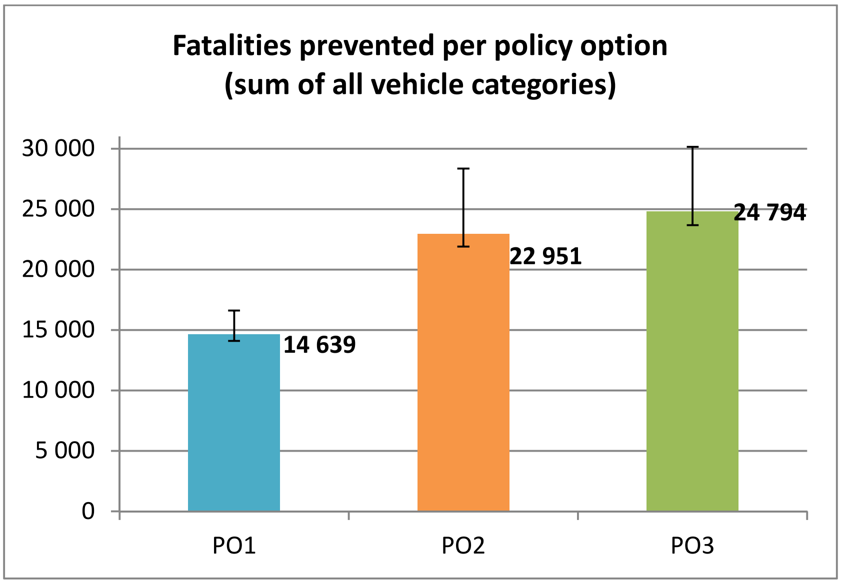

Figure 16: Total sum of fatal casualties prevented by safety measures across all vehicle categories over the evaluation period 2021–2037 across EU-28 compared to the baseline scenario (best estimate with indication of uncertainty ranges from scenario analysis)

Passenger cars (M1):

Table 32: Passenger cars (M1): Total number of casualties prevented by M1 safety measures over the evaluation period 2021–2037 across EU-28 compared to the baseline scenario (best estimate)

Passenger cars (M1)	PO1	PO2	PO3
Fatalities prevented	13,785	20,081	21,337
Serious casualties prevented	63,493	107,913	126,390
Slight casualties prevented	276,815	389,756	470,747

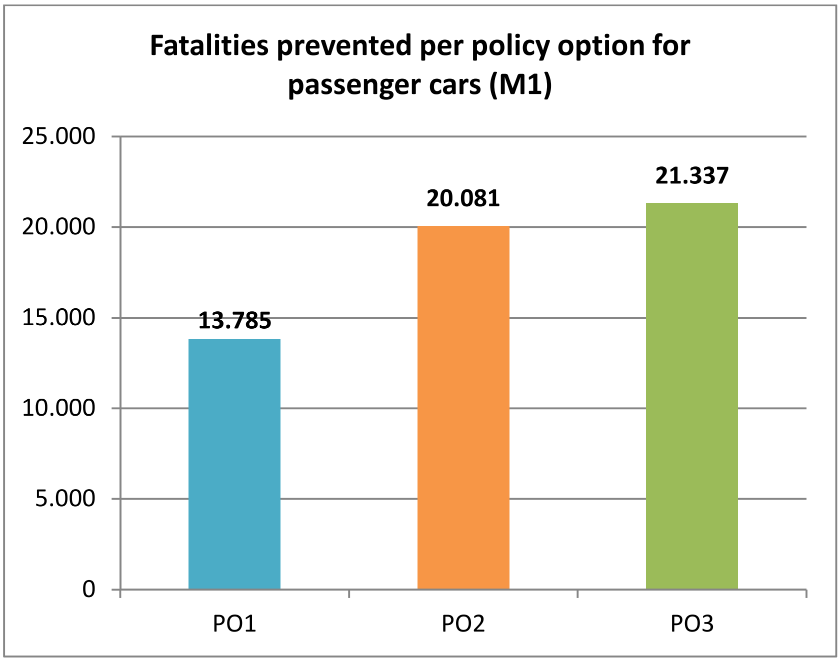

Figure 17: Passenger cars (M1): Total number of fatal casualties prevented by M1 safety measures over the evaluation period 2021–2037 across EU-28 compared to the baseline scenario (best estimate)

Buses and coaches (M2&M3):

Table 33: Buses and coaches (M2&M3): Total number of casualties prevented by M2&M3 safety measures over the evaluation period 2021–2037 across EU-28 compared to the baseline scenario (best estimate)

Buses and coaches (M2&M3)	PO1	PO2	PO3
Fatalities prevented	2	207	227
Serious casualties prevented	33	2,064	2,410
Slight casualties prevented	113	6,421	8,174

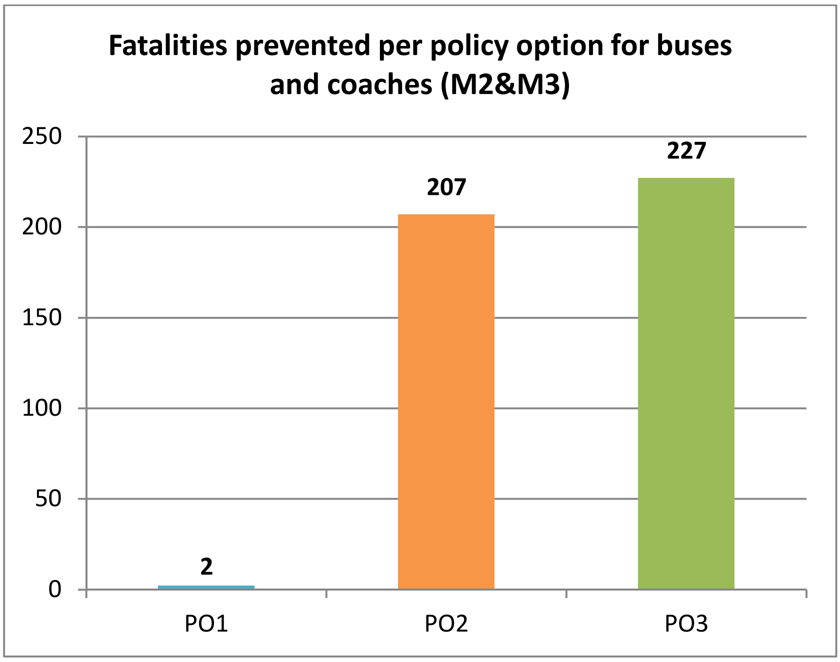

Figure 18: Buses and coaches (M2&M3): Total number of fatal casualties prevented by M2&M3 safety measures over the evaluation period 2021–2037 across EU-28 compared to the baseline scenario (best estimate)

Vans (N1):

Table 34: Vans (N1): Total number of casualties prevented by N1 safety measures over the evaluation period 2021–2037 across EU-28 compared to the baseline scenario (best estimate)

Vans (N1)	PO1	PO2	PO3
Fatalities prevented	852	1,005	1,283
Serious casualties prevented	4,074	5,068	6,917
Slight casualties prevented	11,208	15,536	23,486

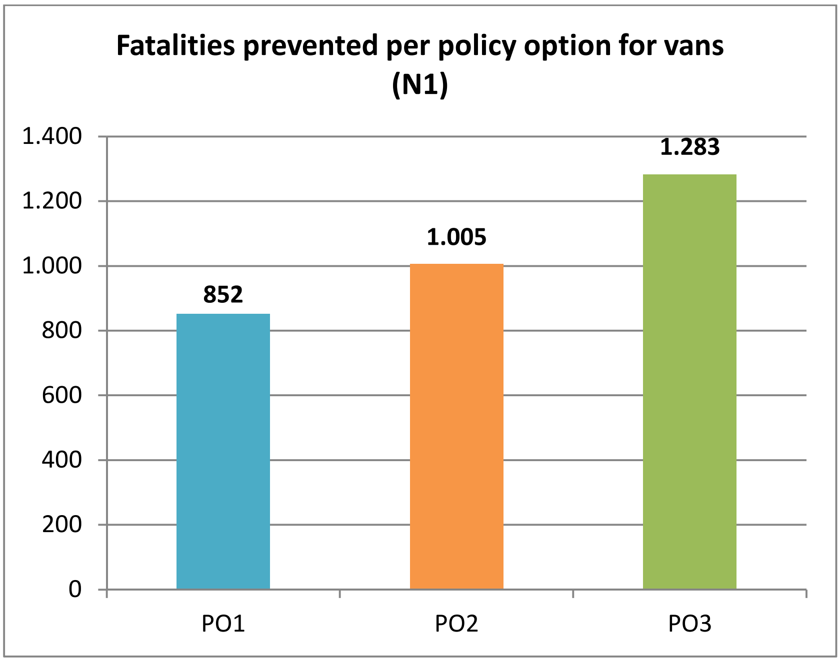

Figure 19: Vans (N1): Total number of fatal casualties prevented by N1 safety measures over the evaluation period 2021–2037 across EU-28 compared to the baseline scenario (best estimate)

Trucks (N2&N3):

Table 35: Trucks (N2&N3): Total number of casualties prevented by N2&N3 safety measures over the evaluation period 2021–2037 across EU-28 compared to the baseline scenario (best estimate)

Trucks (N2&N3)	PO1	PO2	PO3
Fatalities prevented	0	1,658	1,947
Serious casualties prevented	47	3,888	5,023
Slight casualties prevented	157	9,849	13,274

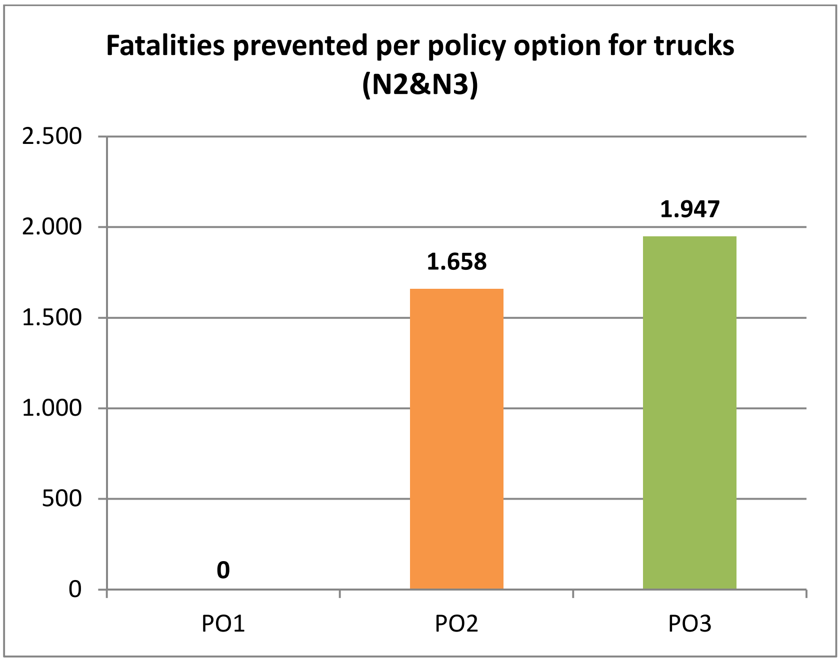

Figure 20: Trucks (N2&N3): Total number of fatal casualties prevented by N2&N3 safety measures over the evaluation period 2021–2037 across EU-28 compared to the baseline scenario (best estimate)

Annex 1.6 Conclusions

From the results found for passenger cars (M1) in this cost-effectiveness study, it can be concluded that PO1 offers the most favourable cost-benefit value, but falls short of the overall casualty savings that are expected for implementation of PO2 or PO3 by a considerable margin. PO2 has the potential to prevent approximately 6,296 fatalities more over the evaluation period (2021–2037) compared to PO1 and is cost-effective, with the benefits exceeding the costs by a factor of almost three. PO3 is expected to prevent an additional 1,249 fatalities compared to PO2.

The results for buses and coaches (M2&M3) lead to the following conclusions: PO1 is most cost-beneficial; however, with this policy option consisting of only two measures, the impact of implementation on both costs and benefits would be minimal. PO1 is expected to prevent almost no fatalities. PO2 has a favourable BCR of over 3 and has the potential to prevent 207 fatalities, which could be a reason to favour this policy option over PO1. PO3 would prevent an additional 20 fatalities and is still expected to be cost-beneficial compared to the baseline scenario at a factor of more than two.

For vans (N1), again PO1 is most cost-beneficial, but implementation of PO2, which is exceeding the threshold to cost-effectiveness, offers the potential to prevent an additional 153 fatalities and 994 serious casualties over the period 2021–2037, many of which are pedestrians and cyclists addressed by the measures AEB-PCD and HED-MGI. PO3 falls short of crossing the threshold to cost-effectiveness, with the costs exceeding the benefits with a factor of almost two, but would be expected to prevent another 278 fatalities and 1,849 serious casualties compared to PO2.

The conclusions for trucks (N2&N3) differ from those for buses and coaches, in that PO1 was found not to be cost-effective. However, it should be considered that PO1 has minimal costs associated with it (two measures) and therefore small differences in the target populations and resulting benefits cause large fluctuations in the ratio. PO2 is the most favourable option for trucks based on BCR and would prevent 1,658 fatalities. PO3 offers the potential to prevent an additional 289 fatalities, with the benefits exceeding the costs by only a small margin.

Overall it can be concluded that PO1 offers mostly favourable cost-effectiveness ratios; however, these are achieved with only a small impact on both the costs and the benefits compared to the baseline scenario of continued voluntary uptake. The impacts of PO2 and PO3 are larger, with numbers of fatalities prevented exceeding those of PO1 by a considerable margin; however this is accompanied by a greater cost. Where PO2 or PO3 exceed the threshold to cost-effectiveness (BCR>1), the considerably greater number of casualties prevented compared to PO1 could be a reason to favour implementation of PO2 or PO3.

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Annex 1.8 Appendices of input values

Annex 1.8.1 General road casualty trend

Table 36: General road casualty trend, EU-28 casualties per annum; historic numbers for 2011–2016, future projections provided by European Commission for 2017–2037

Year	Best estimate			Lower estimate		
	Fatal casualties	Serious casualties	Slight casualties	Fatal casualties	Serious casualties	Slight casualties
2011	30,685	264,929	1,235,015	30,685	264,929	1,235,015
2012	28,243	247,661	1,193,873	28,243	247,661	1,193,873
2013	25,956	240,039	1,156,475	25,956	240,039	1,156,475
2014	25,977	250,051	1,173,515	25,977	250,051	1,173,515
2015	26,130	247,905	1,180,068	26,130	247,905	1,180,068
2016	25,619	246,127	1,207,268	25,619	246,127	1,207,268
2017	25,619	246,127	1,207,268	25,440	244,404	1,198,817
2018	25,619	246,127	1,207,268	25,262	242,693	1,190,426
2019	25,619	246,127	1,207,268	25,085	240,994	1,182,093
2020	25,619	246,127	1,207,268	24,909	239,307	1,173,818
2021	25,619	246,127	1,207,268	24,735	237,632	1,165,601
2022	25,619	246,127	1,207,268	24,562	235,969	1,157,442
2023	25,619	246,127	1,207,268	24,390	234,317	1,149,340
2024	25,619	246,127	1,207,268	24,219	232,677	1,141,295
2025	25,619	246,127	1,207,268	24,049	231,048	1,133,306
2026	25,619	246,127	1,207,268	23,881	229,431	1,125,373
2027	25,619	246,127	1,207,268	23,714	227,825	1,117,495
2028	25,619	246,127	1,207,268	23,548	226,230	1,109,672
2029	25,619	246,127	1,207,268	23,383	224,646	1,101,905

Year	Best estimate			Lower estimate		
	Fatal casualties	Serious casualties	Slight casualties	Fatal casualties	Serious casualties	Slight casualties
2030	25,619	246,127	1,207,268	23,219	223,074	1,094,191
2031	25,619	246,127	1,207,268	23,057	221,512	1,086,532
2032	25,619	246,127	1,207,268	22,896	219,962	1,078,926
2033	25,619	246,127	1,207,268	22,735	218,422	1,071,374
2034	25,619	246,127	1,207,268	22,576	216,893	1,063,874
2035	25,619	246,127	1,207,268	22,418	215,375	1,056,427
2036	25,619	246,127	1,207,268	22,261	213,867	1,049,032
2037	25,619	246,127	1,207,268	22,105	212,370	1,041,689

Annex 1.8.2 Layers of proposed and existing safety measures

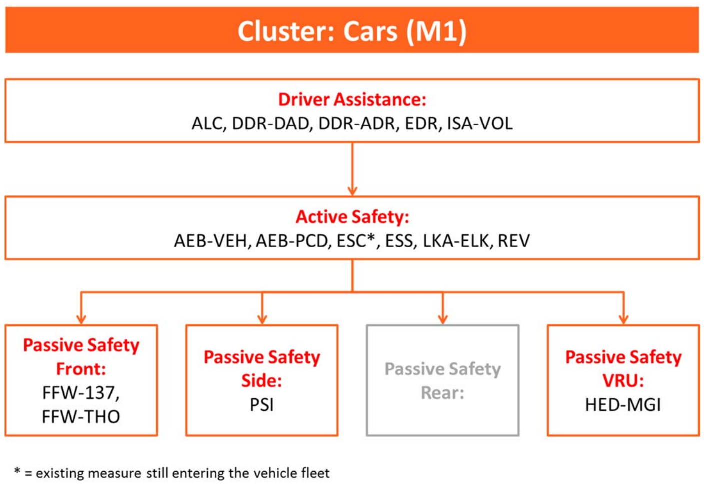

Figure 21: Measure layers for cluster cars (M1)

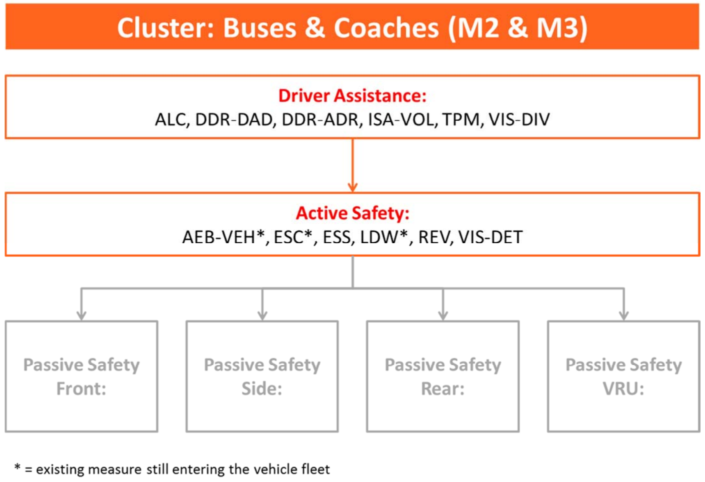

Figure 22: Measure layers for cluster buses and coaches (M2&M3)

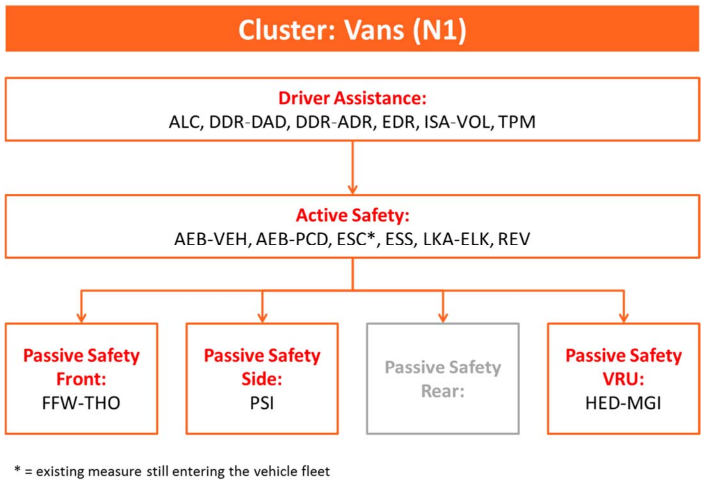

Figure 23: Measure layers for cluster vans (N1)

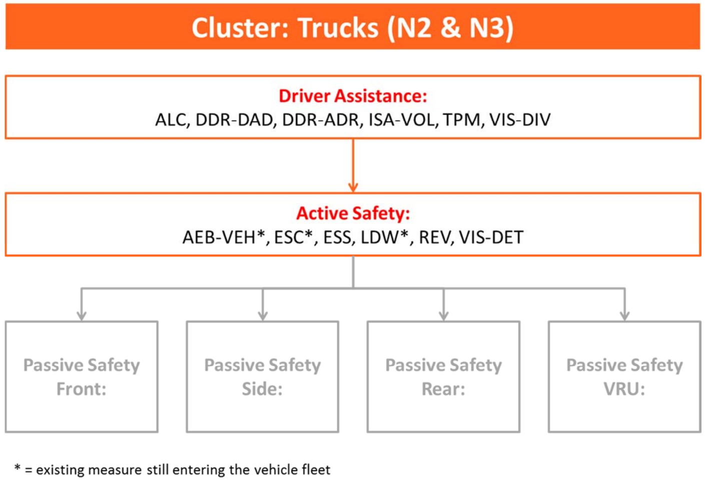

Figure 24: Measure layers for cluster trucks (N2&N3)

Annex 1.8.3 Vehicle fleet size

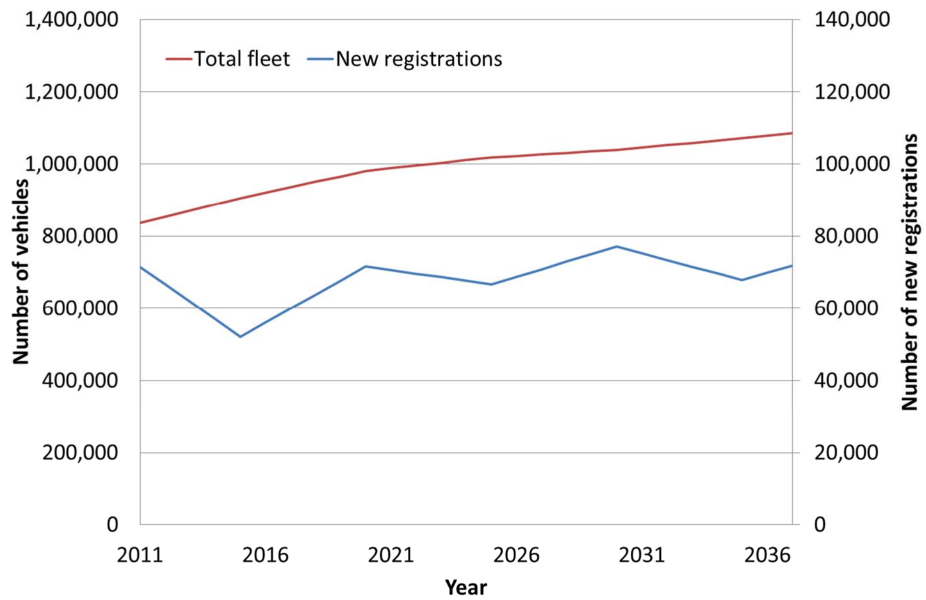

Figure 25: Bus and coach (M2 and M3) fleet and new registrations 2011 to 2037

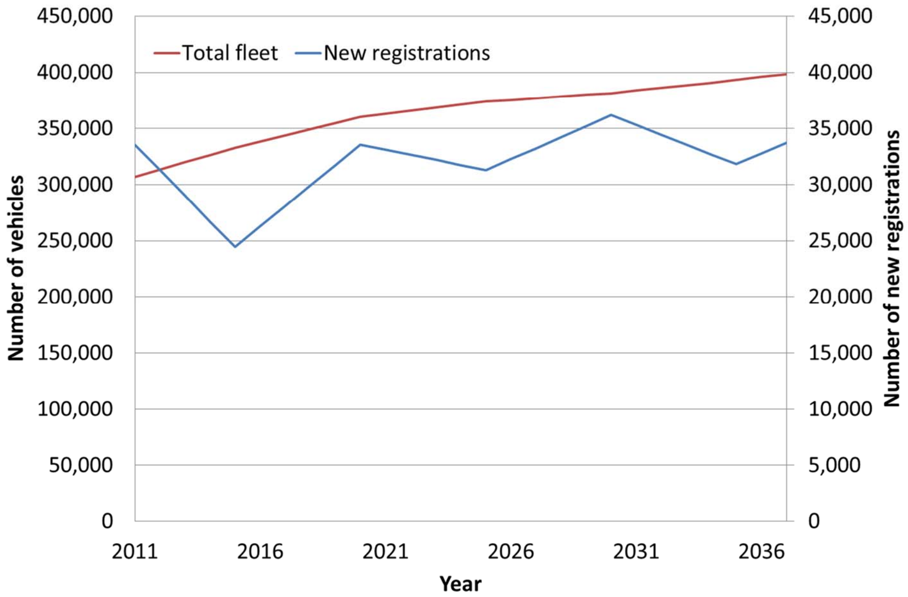

Figure 26: Extra-urban bus and coach fleet and new registrations 2011 to 2037

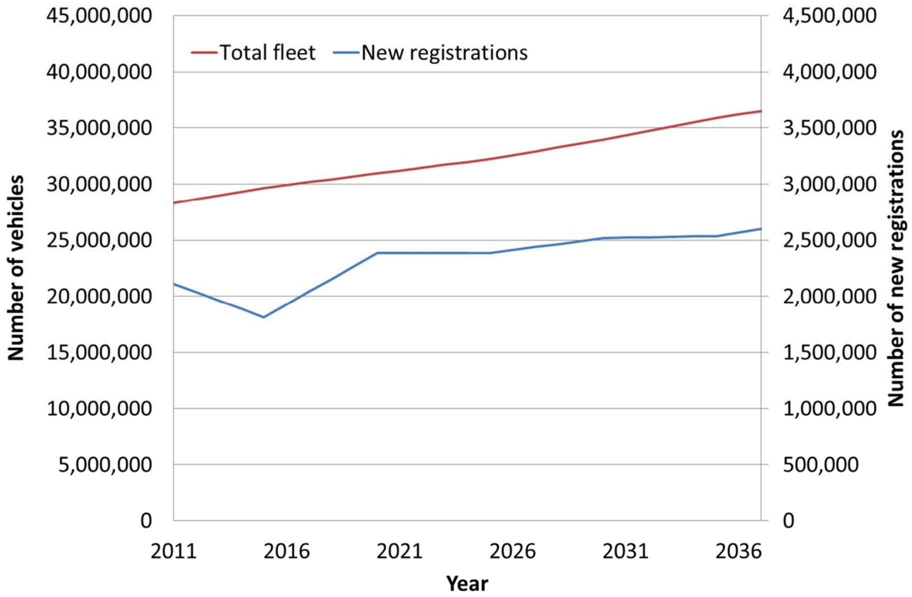

Figure 27: Van (N1) fleet and new registrations 2011 to 2037

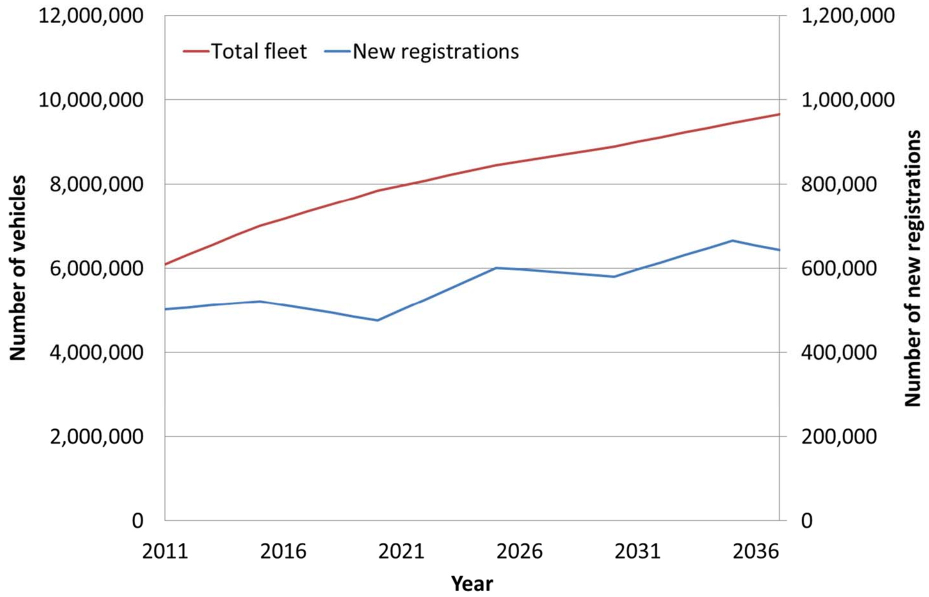

Figure 28: Truck (N2 and N3) fleet and new registrations 2011 to 2037

Annex 1.8.4 Fleet dispersion of safety measures

Table 37: Technology launch date

	M1	M2&M3	N1	N2&N3	Source / justification
AEB-VEH	2009	2009	2009	2009	Introduced before 2011 (Seidl, et al., 2017), 2009 provides the closest link to third-party observations on fleet fitment rates in 2015 (i.e. 32% of newly registered cars in the Netherlands, 30% in Belgium, 16% in Spain and 21% in the United Kingdom).
AEB-PCD (pedestrian)	2012	n/a	2012	n/a	Launch date in first motor cars (e.g. Volvo).
AEB-PCD (cyclist)	2015	n/a	2015	n/a	Launch date in first motor cars (e.g. Volvo).
ALC	2019	2019	2019	2019	Time needed to develop the installation document and to see alcohol interlocks developed to match the specifications.
DDR-DAD	2011	2011	2011	2011	Systems recognised by Euro NCAP (e.g. Ford Driver Alert).
DDR-ADR	2018	2018	2018	2018	Close to market, but no evidence of launch, yet (Seidl, et al., 2017).
EDR	2006	n/a	2006	n/a	Initial cost/benefit study date.
ESC	1996	1996	1996	1996	1996 is probably too early for trucks and buses but is intended to reflect the launch date of the first example, and predominantly relating to the car fleet uptake.
ESS	2010	2010	2010	2010	System evaluation cited by (Seidl, et al., 2017).
FFW-137	2008	n/a	2008	n/a	
FFW-THO	2012	n/a	2012	n/a	
HED-MGI	2009	n/a	2009	n/a	Monitoring phase for headform-to-windscreen tests in Pedestrian Safety Regulation (EC) No 78/2009.
ISA-VOL	2015	2015	2015	2015	This matches the release date for vehicles such as the Ford S-Max with its voluntary ISA system.
LDW	n/a	2011	n/a	2011	NHTSA and TRL studies suggest launch dates about 2011.
LKA-ELK	2018	n/a	2018	n/a	Suggested launch date according to GSR2 stakeholder input (Seidl, et al., 2017).
PSI	2001	n/a	2001	n/a	
REV	2010	2010	2010	2010	(NHTSA, 2010)
TPM	n/a	2005	2005	2005	(Seidl, et al., 2017)
VIS-DET	n/a	2016	n/a	2016	Mercedes-Benz Active Brake Assist 4 was introduced in December 2016 and it offers functionality including (and exceeding) that required for this measure (Seidl, et al., 2017).
VIS-DIV	n/a	2017	n/a	2017	The topic of heavy vehicle direct vision starting to gain momentum amongst operators and vehicle manufacturers (e.g. announcement of direct vision standard for London).

Table 38: Full voluntary implementation year for new registrations

	M1	M2&M3	N1	N2&N3
AEB-VEH	2023	2023	2023	2023
AEB-PCD (pedestrian)	2026	n/a	2026	n/a
AEB-PCD (cyclist)	2029	n/a	2029	n/a
ALC	2033	2033	2033	2033
DDR-DAD	2025	2025	2025	2025
DDR-ADR	2032	2032	2032	2032
EDR	2012	n/a	2016	n/a
ESC	2006	2006	2006	2006
ESS	2024	2024	2024	2024
FFW-137	2014	n/a	2014	n/a
FFW-THO	2026	n/a	2026	n/a
HED-MGI	2023	n/a	2023	n/a
ISA-VOL	2029	2029	2029	2029
LDW	n/a	2025	n/a	2025
LKA-ELK	2032	n/a	2032	n/a
PSI	2015	n/a	2015	n/a
REV	2024	2024	2024	2024
TPM	n/a	2019	2019	2019
VIS-DET	n/a	2030	n/a	2030
VIS-DIV	n/a	2031	n/a	2031

Table 39: Voluntary implementation uptake for new registrations

	M1	M2&M3	N1	N2&N3
AEB-VEH	High	High	High	High
AEB-PCD (pedestrian)	High	n/a	Medium	n/a
AEB-PCD (cyclist)	High	n/a	Medium	n/a
ALC	None	None	None	None
DDR-DAD	Medium	Medium	Medium	Medium
DDR-ADR	None	None	None	None
EDR	Medium	n/a	Medium	n/a
ESC	High	High	High	High
ESS	High	High	High	High
FFW-137	High	n/a	Medium	n/a
FFW-THO	High	n/a	Medium	n/a
HED-MGI	None	n/a	None	n/a
ISA-VOL	None	None	None	None
LDW	n/a	High	n/a	High
LKA-ELK	Medium	n/a	Medium	n/a
PSI	High	n/a	None	n/a
REV	Medium	None	Medium	None
TPM	n/a	None	None	None
VIS-DET	n/a	None	n/a	None
VIS-DIV	n/a	Medium	n/a	Medium

Annex 1.8.5 Target population descriptions for accident data extracts

Table 40: Target population descriptions for proposed measures for all vehicle categories

Measure	Target population description for extract from police reported data	Correction factors subsequently applied in order to …	Correction factor fatal	Correction factor serious	Correction factor slight
AEB-VEH	Casualties in two-motor-vehicle (excluding powered two-wheelers) front-to-rear collisions.	None.	1	1	1
AEB-PCD	Pedestrian and cyclist casualties in impacts with vehicle front.	None.	1	1	1
ALC	Casualties where the driver being impaired by alcohol contributed to the collision.	… narrow the target population down to only those alcohol-related collisions which were caused by hard-core drink drivers (repeat offenders) (Seidl, et al., 2017).	0.75	0.75	0.75
DDR-DAD	Casualties in collisions, where drowsiness or long lasting inattention/distraction contributed to the collision.	… account for underreporting of relevant contributory factors (TRL expert panel estimate).	2.00	4.00	4.00
DDR-ADR	Casualties in collisions, where drowsiness or long lasting or short-term inattention/distraction contributed to the collision.	… account for underreporting of relevant contributory factors (TRL expert panel estimate).	2.00	4.00	4.00
EDR	Car and van occupant casualties in all motor vehicle collisions.	None.	1	1	1
ESS	Casualties in two-motor-vehicle (excluding powered two-wheelers) front-to-rear collisions on roads with a speed limit exceeding 30 mph, where sudden braking of the vehicle in front contributed to the collision.	… account for underreporting of relevant contributory factors (TRL expert panel estimate).	4.50	4.50	4.50
FFW-137	Front seat casualties in frontal impacts.	… narrow the target population down to only full-width impacts with thorax injuries (Seidl, et al., 2017).	0.0825	0.0825	0.0825
FFW-THO	Front seat casualties in frontal impacts.	… narrow the target population down to only full-width impacts with thorax injuries (Seidl, et al., 2017).	0.0825	0.0825	0.0825
HED-MGI	Pedestrian and cyclist casualties in impacts with vehicle front.	… narrow target population down to those casualties who suffered serious head injuries from impact with the glazed area of the windscreen more than 10 centimetres away from the scuttle, A-pillars, and header rail; TRL calculations based on GIDAS data (ACEA TF-ACC, 2017e).	0.025875	0.020493	0

Measure	Target population description for extract from police reported data	Correction factors subsequently applied in order to …	Correction factor fatal	Correction factor serious	Correction factor slight
ISA-VOL	Casualties in collisions where the driver exceeding the speed limit contributed to the collision and there were no other contributory factors that indicated poor compliance of the driver with the law (e.g. impaired by alcohol/drugs, uncorrected eyesight, using mobile phone, stolen vehicle, etc.).	… (account for underreporting of contributory factor 'exceeding the speed limit' in Stats19) x (adjust to average population in Germany and UK (ACEA TF-ACC, 2017a), (ACEA TF-ACC, 2017b)).	M1/N1: 4.50x0.99 M2&M3/N2&N3: 4.50x1.64	M1/N1: 4.50x1.18 M2&M3/N2&N3: 4.50x5.50	M1/N1: 4.50x1.12 M2&M3/N2&N3: 4.50x4.50
LKA-ELK	Casualties in head-on and single-vehicle crashes on roads with speed limits between 70 km/h and 120 km/h (40 mph and 70 mph) and dry or wet road surfaces (i.e. not covered by ice or snow).	None.	1	1	1
PSI	Front seat casualties in lateral impacts against narrow objects (e.g. trees, lampposts, traffic signals, etc.).	None.	1	1	1
REV	Pedestrian and cyclist casualties caused by a reversing motor vehicle.	… (account for collisions that happen away from public roads and are therefore not included in official road casualty statistics (Seidl, et al., 2017)) x (adjust to average population in France, Germany and UK (ACEA TF-ACC, 2017c)).	M1/N1: 2.00 M2&M3/N2&N3: 2.00x1.25	M1/N1: 2.00 M2&M3/N2&N3: 2.00x1.08	M1/N1: 2.00 M2&M3/N2&N3: 2.00x1.00
TPM	Casualties where illegal, defective or under-inflated tyres contributed to the collision.	… narrow the target population down to only those collisions where under-inflated tyres contributed (TRL expert panel estimate).	0.25	0.25	0.25
VIS-DET	For N2&N3: Pedestrian and cyclist casualties in impacts with vehicle front or side. For M2&M3: Pedestrian and cyclist casualties in impacts with vehicle front or side where a vehicle blind spot contributed to the collision. Note: The narrower target population definition for buses and coaches is necessary to make meaningful effectiveness estimates, because the current direct vision of these vehicles is considerably better than that of trucks.	… adjust to average population in France, Germany and UK (ACEA TF-ACC, 2017d).	0.80	1.21	1.33

Measure	Target population description for extract from police reported data	Correction factors subsequently applied in order to …	Correction factor fatal	Correction factor serious	Correction factor slight
VIS-DIV	For N2&N3: Pedestrian and cyclist casualties in impacts with vehicle front or side. For M2&M3: Pedestrian and cyclist casualties in impacts with vehicle front or side where a vehicle blind spot contributed to the collision. Note: The narrower target population definition for buses and coaches is necessary to make meaningful effectiveness estimates, because the current direct vision of these vehicles is considerably better than that of trucks.	… adjust to average population in France, Germany and UK (ACEA TF-ACC, 2017d).	0.80	1.21	1.33

Table 41: Target population descriptions for existing measures for all vehicle categories

Measure	Target population description for extract from police reported data	Correction factors subsequently applied in order to …	Correction factor fatal	Correction factor serious	Correction factor slight
AEB-VEH	Casualties in two-motor-vehicle (excluding powered two-wheelers) front-to-rear collisions. Note: This is an existing measure for M2&M3 and N2&N3 only.	None.	1	1	1
ESC	Loss of control crashes.	None.	1	1	1
LDW	Casualties in collisions on a dual-carriageway or motorway where the vehicle left the carriageway, or rear-impacted a vehicle on the hard shoulder, or side-swiped vehicle. Note: This is an existing measure for M2&M3 and N2&N3 only.	None.	1	1	1

Annex 1.8.6 Effectiveness

Table 42: Effectiveness of proposed measures for M1 vehicles equipped

Measure	Fatal (avoid)	Fatal (mitigate)	Serious (avoid)	Serious (mitigate)	Slight (avoid)	Confidence	Source / justification
AEB-VEH	19.0%	19.0%	19.0%	19.0%	42.0%	High	(Seidl, et al., 2017). Note: Powered-two wheelers were excluded from the target population, i.e. car/van-to-motorcycle collisions were considered not affected. Recent preliminary research showed that in reality a positive effect is to be expected (Lenkeit & Smith, 2016). The benefit estimates applied are therefore conservative.
AEB-PCD	24.4%	24.4%	21.0%	21.0%	42.1%	High	Effectiveness for pedestrians. (Seidl, et al., 2017) for fatal and serious, expert panel estimate for slight.
AEB-PCD	27.5%	27.5%	16.4%	16.4%	32.8%	High	Effectiveness for cyclists. (Seidl, et al., 2017) for fatal and serious, expert panel estimate for slight.
ALC	4.2%	0.0%	4.2%	0.0%	4.2%	Low	TRL expert panel estimate. Assumption that this measure allows the continuation of alcohol interlock installation programmes for hard core drink drivers. 32.0% percent of the EU-28 population live in countries where such programmes exist; (Elder, et al., 2011) report that around 13% of relevant individuals take part in programmes, with programmes being highly effective while interlocks are installed.
DDR-DAD	16.7%	0.0%	16.7%	0.0%	16.7%	Low	(Seidl, et al., 2017)
DDR-ADR	16.7%	0.0%	16.7%	0.0%	16.7%	Low	(Seidl, et al., 2017). Same effectiveness assumed as for basic DDR-DAD systems, but applied to the extended target population for advanced distraction recognition.
EDR	1.0%	1.0%	1.0%	1.0%	1.0%	Low	TRL expert panel estimate. Nominal number to reflect that there will be anon-zero positive effect for road safety from the possibility to learn from detailed collision records.
ESS	5.0%	20.0%	10.0%	20.0%	20.0%	Low	TRL expert panel estimate. Based on the brake reaction time reductions, referenced in (Seidl, et al., 2017), and resulting reductions in stopping distance and impact speed.
FFW-137	0.0%	5.0%	0.0%	5.0%	0.0%	High	(Seidl, et al., 2017). Effectiveness of making vehicles that would comply with UN Regulation No. 94 (but not with UN Regulation No. 137) compliant with FFW-137. Note: Applied only to a small proportion of the vehicle fleet, which would not meet this requirement yet.
FFW-THO	0.0%	6.0%	0.0%	6.0%	0.0%	High	(Seidl, et al., 2017). Additional effectiveness of making vehicles that would comply with FFW-137 compliant with FFW-THO.

Measure	Fatal (avoid)	Fatal (mitigate)	Serious (avoid)	Serious (mitigate)	Slight (avoid)	Confidence	Source / justification
HED-MGI	0.0%	77.0%	0.0%	48.0%	0.0%	High	Based on data collected during the course of the monitoring phase for headform-to-windscreen tests in Pedestrian Safety Regulation (EC) No 78/2009. The value represents a head-to-glass impact test with a mandatory limit of HIC=1,000, which would reduce the mean result from HIC=727 (current monitoring data) to HIC=550 and result in a relative reduction in injury risk as indicated by the effectiveness values given. Note: Applied only to the narrow corrected target population representing casualties who suffered serious head injuries from impact with the glazed area of the windscreen more than 10 centimetres away from the scuttle, A-pillars, and header rail.
ISA-VOL	19.0%	6.7%	19.0%	8.4%	19.0%	High	TRL calculations based on (Barrow, Edwards, Smith, Khatry, & Kalaiyarasan, 2017) and (ACEA TF-ACC, 2017a).
LKA-ELK	53.0%	0.0%	38.5%	0.0%	38.5%	High	(Sternlund, Strandroth, Rizzi, Lie, & Tingvall, 2017) and (Cicchino, 2017). For serious and slight casualties, an average value between the effectiveness values found by the two studies was used. For fatal casualties, the Sternlund value was used as a conservative estimate because the value found by Cicchino for fatalities (86%) was based on a very small sample of vehicles and therefore considered unreliable. Assumption that emergency-type LKA systems could not or would not be deactivated frequently by drivers.
PSI	0.0%	54.0%	0.0%	54.0%	0.0%	High	(Seidl, et al., 2017) and (Billot, Coulot, Zeitouni, Adalian, & Chauvel, 2013) Note: Applied only to a small proportion of the vehicle fleet, which would not meet this requirement yet.
REV	41.0%	0.0%	41.0%	0.0%	41.0%	High	(Seidl, et al., 2017). Effectiveness for camera-based system.

Table 43: Effectiveness of existing measures for M1 vehicles equipped

Measure	Fatal (avoid)	Fatal (mitigate)	Serious (avoid)	Serious (mitigate)	Slight (avoid)	Confidence	Source / justification
ESC	38.0%	0.0%	21.0%	0.0%	21.0%	High	(Høye, 2011)

Table 44: Effectiveness of proposed measures for M2&M3 vehicles equipped

Measure	Fatal (avoid)	Fatal (mitigate)	Serious (avoid)	Serious (mitigate)	Slight (avoid)	Confidence	Source / justification
ALC	4.2%	0.0%	4.2%	0.0%	4.2%	Low	TRL expert panel estimate. Assumption that this measure allows the continuation of alcohol interlock installation programmes for hard core drink drivers. 32.0% percent of the EU-28 population live in countries where such programmes exist; (Elder, et al., 2011) report that around 13% of relevant individuals take part in programmes, with programmes being highly effective while interlocks are installed.
DDR-DAD	16.7%	0.0%	16.7%	0.0%	16.7%	Low	(Seidl, et al., 2017)
DDR-ADR	16.7%	0.0%	16.7%	0.0%	16.7%	Low	(Seidl, et al., 2017). Same effectiveness assumed as for basic DDR-DAD systems, but applied to the extended target population for advanced distraction recognition.
ESS	5.0%	20.0%	10.0%	20.0%	20.0%	Low	TRL expert panel estimate. Based on the brake reaction time reductions, referenced in (Seidl, et al., 2017), and resulting reductions in stopping distance and impact speed.
ISA-VOL	8.9%	9.1%	1.3%	16.8%	19.9%	High	TRL calculations based on (Barrow, Edwards, Smith, Khatry, & Kalaiyarasan, 2017) and (ACEA TF-ACC, 2017b)
REV	33.3%	0.0%	33.3%	0.0%	33.3%	Low	TRL calculations based on (ACEA TF-ACC, 2017c). Effectiveness for camera-based system.
TPM	33.3%	0.0%	33.3%	0.0%	33.3%	Low	TRL expert panel estimate. Note: Applied to narrow target population.
VIS-DET	39.7%	0.0%	40.0%	0.0%	40.0%	Low	TRL calculations based on (Barrow, Edwards, Smith, Khatry, & Kalaiyarasan, 2017) and (ACEA TF-ACC, 2017d). Effectiveness for front and side vulnerable road user detection and warning (no auto braking). Note: Applied to a considerably more narrowly defined target population than that for N2/N3.
VIS-DIV	24.0%	0.0%	24.0%	0.0%	24.0%	Low	TRL calculations based on (Barrow, Edwards, Smith, Khatry, & Kalaiyarasan, 2017) and (ACEA TF-ACC, 2017d). Effectiveness for best-in-class direct vision approach. Note: Applied to a considerably more narrowly defined target population than that for N2/N3. Note 2: The estimated balance between the effects of detection-warning systems and improved direct vision might shift in reality between the two measures. Human factors research indicates that drivers need visual confirmation of the reason for a warning to respond fully effectively to it (see US research for reversing camera rulemaking, (NHTSA, 2010)). Improvements in direct vision are therefore needed to realise the full benefits modelled for detection-warning systems.

Table 45: Effectiveness of existing measures for M2&M3 vehicles equipped

Measure	Fatal (avoid)	Fatal (mitigate)	Serious (avoid)	Serious (mitigate)	Slight (avoid)	Confidence	Source / justification
AEB-VEH	0.0%	25.0%	0.0%	25.0%	5.0%	Low	(Robinson, Hulshof, Robinson, & Knight, 2010)
ESC	28.5%	0.0%	28.5%	0.0%	28.5%	High	(NHTSA, 2015)
LDW	20.0%	0.0%	20%	0.0%	20.0%	Low	(Robinson, Hulshof, Robinson, & Knight, 2010). Lower end of the prospective effectiveness estimates used to reflect the fact that LDW systems, as defined in UN Regulation No. 130, can be deactivated by drivers.

Table 46: Effectiveness of proposed measures for N1 vehicles equipped

Measure	Fatal (avoid)	Fatal (mitigate)	Serious (avoid)	Serious (mitigate)	Slight (avoid)	Confidence	Source / justification
AEB-VEH	19.0%	19.0%	19.0%	19.0%	42.0%	High	(Seidl, et al., 2017)
AEB-PCD	24.4%	24.4%	21.0%	21.0%	42.1%	High	Effectiveness for pedestrians. (Seidl, et al., 2017) for fatal and serious, expert panel estimate for slight.
AEB-PCD	27.5%	27.5%	16.4%	16.4%	32.8%	High	Effectiveness for cyclists. (Seidl, et al., 2017) for fatal and serious, expert panel estimate for slight.
ALC	4.2%	0.0%	4.2%	0.0%	4.2%	Low	TRL expert panel estimate. Assumption that this measure allows the continuation of alcohol interlock installation programmes for hard core drink drivers. 32.0% percent of the EU-28 population live in countries where such programmes exist; (Elder, et al., 2011) report that around 13% of relevant individuals take part in programmes, with programmes being highly effective while interlocks are installed.
DDR-DAD	16.7%	0.0%	16.7%	0.0%	16.7%	Low	(Seidl, et al., 2017)
DDR-ADR	16.7%	0.0%	16.7%	0.0%	16.7%	Low	(Seidl, et al., 2017). Same effectiveness assumed as for basic DDR-DAD systems, but applied to the extended target population for advanced distraction recognition.
EDR	1.0%	1.0%	1.0%	1.0%	1.0%	Low	TRL expert panel estimate. Nominal number to reflect that there will be anon-zero positive effect for road safety from the possibility to learn from detailed collision records.
ESS	5.0%	20.0%	10.0%	20.0%	20.0%	Low	TRL expert panel estimate. Based on the brake reaction time reductions, referenced in (Seidl, et al., 2017), and resulting reductions in stopping distance and impact speed.
FFW-137	0.0%	5.0%	0.0%	5.0%	0.0%	High	(Seidl, et al., 2017). Effectiveness of making vehicles that would comply with UN Regulation No. 94 (but not with UN Regulation No. 137) compliant with FFW-137. Note: Applied only to a small proportion of the vehicle fleet, which would not meet this requirement yet.
FFW-THO	0.0%	6.0%	0.0%	6.0%	0.0%	High	(Seidl, et al., 2017). Additional effectiveness of making vehicles that would comply with FFW-137 compliant with FFW-THO.

Measure	Fatal (avoid)	Fatal (mitigate)	Serious (avoid)	Serious (mitigate)	Slight (avoid)	Confidence	Source / justification
HED-MGI	0.0%	77.0%	0.0%	48.0%	0.0%	Low	Based on data collected during the course of the monitoring phase for headform-to-windscreen tests on cars in Pedestrian Safety Regulation (EC) No 78/2009 (therefore reduced confidence for vans). The value represents a head-to-glass impact test with a mandatory limit of HIC=1,000, which would reduce the mean result from HIC=727 (current monitoring data) to HIC=550 and result in a relative reduction in injury risk as indicated by the effectiveness values given. Note: Applied only to the narrow corrected target population representing casualties who suffered serious head injuries from impact with the glazed area of the windscreen more than 10 centimetres away from the scuttle, A-pillars, and header rail.
ISA-VOL	19.0%	6.7%	19.0%	8.4%	19.0%	High	TRL calculations based on (Barrow, Edwards, Smith, Khatry, & Kalaiyarasan, 2017) and (ACEA TF-ACC, 2017a).
LKA-ELK	53.0%	0.0%	38.5%	0.0%	38.5%	High	(Sternlund, Strandroth, Rizzi, Lie, & Tingvall, 2017) and (Cicchino, 2017) (studies for M1 vehicles, best available evidence). For serious and slight casualties, an average value between the effectiveness values found by the two studies was used. For fatal casualties, the Sternlund value was used as a conservative estimate because the value found by Cicchino for fatalities (86%) was based on a very small sample of vehicles and therefore considered unreliable. Assumption that emergency-type LKA systems could not or would not be deactivated frequently by drivers.
PSI	0.0%	54.0%	0.0%	54.0%	0.0%	High	(Seidl, et al., 2017) and (Billot, Coulot, Zeitouni, Adalian, & Chauvel, 2013) Note: Applied only to a small proportion of the vehicle fleet, which would not meet this requirement yet.
REV	41.0%	0.0%	41.0%	0.0%	41.0%	High	(Seidl, et al., 2017). Effectiveness for camera-based system.
TPM	33.3%	0.0%	33.3%	0.0%	33.3%	Low	TRL expert panel estimate. Note: Applied to narrow target population.

Table 47: Effectiveness of existing measures for N1 vehicles equipped

Measure	Fatal (avoid)	Fatal (mitigate)	Serious (avoid)	Serious (mitigate)	Slight (avoid)	Confidence	Source / justification
ESC	38.0%	0.0%	21.0%	0.0%	21.0%	High	(Høye, 2011)

Table 48: Effectiveness of proposed measures for N2&N3 vehicles equipped

Measure	Fatal (avoid)	Fatal (mitigate)	Serious (avoid)	Serious (mitigate)	Slight (avoid)	Confidence	Source / justification
ALC	4.2%	0.0%	4.2%	0.0%	4.2%	Low	TRL expert panel estimate. Assumption that this measure allows the continuation of alcohol interlock installation programmes for hard core drink drivers. 32.0% percent of the EU-28 population live in countries where such programmes exist; (Elder, et al., 2011) report that around 13% of relevant individuals take part in programmes, with programmes being highly effective while interlocks are installed.
DDR-DAD	16.7%	0.0%	16.7%	0.0%	16.7%	Low	(Seidl, et al., 2017)
DDR-ADR	16.7%	0.0%	16.7%	0.0%	16.7%	Low	(Seidl, et al., 2017). Same effectiveness assumed as for basic DDR-DAD systems, but applied to the extended target population for advanced distraction recognition.
ESS	5.0%	20.0%	10.0%	20.0%	20.0%	Low	TRL expert panel estimate. Based on the brake reaction time reductions, referenced in (Seidl, et al., 2017), and resulting reductions in stopping distance and impact speed.
ISA-VOL	8.9%	9.1%	1.3%	16.8%	19.9%	High	TRL calculations based on (Barrow, Edwards, Smith, Khatry, & Kalaiyarasan, 2017) and (ACEA TF-ACC, 2017b)
REV	33.3%	0.0%	33.3%	0.0%	33.3%	Low	TRL calculations based on (ACEA TF-ACC, 2017c). Effectiveness for camera-based system.
TPM	33.3%	0.0%	33.3%	0.0%	33.3%	Low	TRL expert panel estimate. Note: Applied to narrow target population.
VIS-DET	39.7%	0.0%	40.0%	0.0%	40.0%	High	(Barrow, Edwards, Smith, Khatry, & Kalaiyarasan, 2017) and (ACEA TF-ACC, 2017d). Effectiveness for front and side vulnerable road user detection and warning (no auto braking).
VIS-DIV	2.9%	0.0%	2.9%	0.0%	3.0%	High	(Barrow, Edwards, Smith, Khatry, & Kalaiyarasan, 2017) and (ACEA TF-ACC, 2017d). Effectiveness for best-in-class direct vision approach. Note: The estimated balance between the effects of detection-warning systems and improved direct vision might shift in reality between the two measures. Human factors research indicates that drivers need visual confirmation of the reason for a warning to respond fully effectively to it (see US research for reversing camera rulemaking, (NHTSA, 2010)). Improvements in direct vision are therefore needed to realise the full benefits modelled for detection-warning systems.

Table 49: Effectiveness of existing measures for N2&N3 vehicles equipped

Measure	Fatal (avoid)	Fatal (mitigate)	Serious (avoid)	Serious (mitigate)	Slight (avoid)	Confidence	Source / justification
AEB-VEH	0.0%	25.0%	0.0%	25.0%	5.0%	Low	(Robinson, Hulshof, Robinson, & Knight, 2010)
ESC	28.5%	0.0%	28.5%	0.0%	28.5%	High	(NHTSA, 2015)
LDW	20.0%	0.0%	20%	0.0%	20.0%	Low	(Robinson, Hulshof, Robinson, & Knight, 2010). Lower end of the prospective effectiveness estimates used to reflect the fact that LDW systems, as defined in UN Regulation No. 130, can be deactivated by drivers.

Annex 1.8.7 Costs

Table 50: Initial cost at mandatory introduction of proposed measures for M1 vehicles. Cost estimate in € per vehicle equipped for the given year (subject to inflation). Estimated development and fixed production costs are included and spread equally across vehicles.

Measure	Cost (best estimate)	Cost (lower estimate)	Cost (upper estimate)	in year	Source / justification
AEB-VEH	€44	€35	€53	2012	(Seidl, et al., 2017) under consideration of industry input. The cost reflects the apportioned share of the total cost for a system that shares sensor technology to deliver four measures: AEB-VEH, AEB-PCD, ISA-VOL and LKA-ELK.
AEB-PCD	€54	€43	€65	2012	(Seidl, et al., 2017) under consideration of industry input. The cost reflects the apportioned share of the total cost for a system that shares sensor technology to deliver four measures: AEB-VEH, AEB-PCD, ISA-VOL and LKA-ELK.
ALC	€2	€1	€5	2020	(Seidl, et al., 2017) under consideration of industry input. Cost of an alcohol interlock installation sheet. The cost for equipping any vehicles with alcohol interlocks, made possible by this measure would be carried by the drivers affected.
DDR-DAD	€9	€8	€10	2020	(Seidl, et al., 2017). Cost of a system based on existing sensors, such as steering wheel input.
DDR-ADR	€110	€98	€150	2020	(Seidl, et al., 2017) under consideration of industry input. Cost of a system based on driver-facing sensor hardware, such as camera.
EDR	€2	€1	€5	2020	(Seidl, et al., 2017) under consideration of industry input. Cost for a Part-563-type EDR. Equivalent hardware already available on most vehicles, but recordings are not readable.
ESS	€1	€0	€2	2020	(Seidl, et al., 2017). Nominal cost for software-based system (validation and testing).
FFW-137	€32	€26	€38	2008	(Seidl, et al., 2017). Cost for vehicles that comply with UN Regulation No. 94 but not with UN Regulation No. 137.
FFW-THO	€16	€13	€19	2008	(Seidl, et al., 2017). Additional cost for vehicles that comply with UN Regulation No. 137 with Hybrid III ATDs but not with THOR-M ATDs.
HED-MGI	€5	€2	€20	2020	TRL expert panel estimate for cost of adapting the glazed area of windscreens to comply with a mandatory HIC limit in head-to-glass impact tests. Assumption that this cost is mostly made up of research and development efforts by glass suppliers, with only a small increase in ongoing production costs.
ISA-VOL	€59	€47	€71	2012	(Seidl, et al., 2017) under consideration of industry input. The cost reflects the apportioned share of the total cost for a system that shares sensor technology to deliver four measures: AEB-VEH, AEB-PCD, ISA-VOL and LKA-ELK. Additional cost added for actuators required.
LKA-ELK	€70	€56	€84	2012	(Seidl, et al., 2017) under consideration of industry input. The cost reflects the apportioned share of the total cost for a system that shares sensor technology to deliver four measures: AEB-VEH, AEB-PCD, ISA-VOL and LKA-ELK. Additional cost added for actuators required.

Measure	Cost (best estimate)	Cost (lower estimate)	Cost (upper estimate)	in year	Source / justification
PSI	€30	€20	€40	2020	TRL expert panel estimate under consideration of industry input for cost of making vehicle compliant with UN Regulation No. 135, which do not meet the requirements yet.
REV	€40	€25	€55	2012	(Seidl, et al., 2017) under consideration of industry input. Cost of a camera-based system using an existing display.

Table 51: Initial cost at mandatory introduction of proposed measures for M2&M3 vehicles. Cost estimate in € per vehicle equipped for the given year (subject to inflation). Estimated development and fixed production costs are included and spread equally across vehicles.

Measure	Cost (best estimate)	Cost (lower estimate)	Cost (upper estimate)	in year	Source / justification
ALC	€4	€2	€6	2020	(Seidl, et al., 2017) under consideration of industry input provided for other heavy vehicles (N2&N3). Cost of an alcohol interlock installation sheet. The cost for equipping any vehicles with alcohol interlocks, made possible by this measure would be carried by the drivers affected.
DDR-DAD	€20	€10	€50	2020	(Seidl, et al., 2017) under consideration of industry input provided for other heavy vehicles (N2&N3). Cost of a system based on existing sensors, such as steering wheel input.
DDR-ADR	€165	€147	€225	2020	(Seidl, et al., 2017) under consideration of industry input provided for other heavy vehicles (N2&N3). Cost of a system based on driver-facing sensor hardware, such as camera.
ESS	€2	€0	€4	2020	(Seidl, et al., 2017). Nominal cost for software-based system (validation and testing).
ISA-VOL	€110	€92	€124	2012	(Seidl, et al., 2017) under consideration of industry input provided for other heavy vehicles (N2&N3).
REV	€125	€106	€144	2012	(Seidl, et al., 2017). Cost of full system including camera and display.
TPM	€52	€44	€60	2013	(van Zyl, van Goethem, Kanarachos, Rexeis, Hausberger, & Smokers, 2013) and (Seidl, et al., 2017). Cost of a direct TPM solution.
VIS-DET	€300	€150	€500	2020	TRL expert panel estimate under consideration of industry input provided for other heavy vehicles (N2&N3) and (Martin, Knight, Hunt, O'Connell, Cuerden, & McCarthy, 2017). Cost of front and side vulnerable road user detection and warning (no auto braking)
VIS-DIV	€150	€100	€450	2020	TRL expert panel estimate under consideration of industry input provided for other heavy vehicles (N2&N3). Cost for best-in-class approach, i.e. adjustments of existing cabs. Requirement only applies to new types of vehicles, i.e. any cost incurred will partially be absorbed in cab re-design for new vehicle generation (no redesign cost for existing models). This is reflected in a cost estimate reflecting the lower end of estimates from industry input.

Table 52: Initial cost at mandatory introduction of proposed measures for N1 vehicles. Cost estimate in € per vehicle equipped for the given year (subject to inflation). Estimated development and fixed production costs are included and spread equally across vehicles.

Measure	Cost (best estimate)	Cost (lower estimate)	Cost (upper estimate)	in year	Source / justification
AEB-VEH	€44	€35	€53	2012	(Seidl, et al., 2017) under consideration of industry input provided for other light vehicles (M1). The cost reflects the apportioned share of the total cost for a system that shares sensor technology to deliver four measures: AEB-VEH, AEB-PCD, ISA-VOL and LKA-ELK.
AEB-PCD	€54	€43	€65	2012	(Seidl, et al., 2017) under consideration of industry input provided for other light vehicles (M1). The cost reflects the apportioned share of the total cost for a system that shares sensor technology to deliver four measures: AEB-VEH, AEB-PCD, ISA-VOL and LKA-ELK.
ALC	€2	€1	€5	2020	(Seidl, et al., 2017) under consideration of industry input provided for other light vehicles (M1). Cost of an alcohol interlock installation sheet. The cost for equipping any vehicles with alcohol interlocks, made possible by this measure would be carried by the drivers affected.
DDR-DAD	€9	€8	€10	2020	(Seidl, et al., 2017). Cost of a system based on existing sensors, such as steering wheel input.
DDR-ADR	€110	€98	€150	2020	(Seidl, et al., 2017) under consideration of industry input provided for other light vehicles (M1). Cost of a system based on driver-facing sensor hardware, such as camera.
EDR	€2	€1	€5	2020	(Seidl, et al., 2017) under consideration of industry input provided for other light vehicles (M1). Cost for a Part-563-type EDR. Equivalent hardware already available on most vehicles, but recordings are not readable.
ESS	€1	€0	€2	2020	(Seidl, et al., 2017). Nominal cost for software-based system (validation and testing).
FFW-137	€32	€26	38	2008	(Seidl, et al., 2017). Cost for vehicles that comply with UN Regulation No. 94 but not with UN Regulation No. 137.
FFW-THO	€16	€13	€19	2008	(Seidl, et al., 2017). Cost for vehicles that comply with UN Regulation No. 137 with Hybrid III ATDs but not with THOR-M ATDs.
HED-MGI	€5	€2	€20	2020	TRL expert panel estimate for cost of adapting the glazed area of windscreens to comply with a mandatory HIC limit in head-to-glass impact tests. Assumption that this cost is mostly made up of research and development efforts by glass suppliers, with only a small increase in ongoing production costs.
ISA-VOL	€59	€47	€71	2012	(Seidl, et al., 2017) under consideration of industry input provided for other light vehicles (M1). The cost reflects the apportioned share of the total cost for a system that shares sensor technology to deliver four measures: AEB-VEH, AEB-PCD, ISA-VOL and LKA-ELK. Additional cost added for actuators required.
LKA-ELK	€70	€56	€84	2012	(Seidl, et al., 2017) under consideration of industry input provided for other light vehicles (M1). The cost reflects the apportioned share of the total cost for a system that shares sensor technology to deliver four measures: AEB-VEH, AEB-PCD, ISA-VOL and LKA-ELK. Additional cost added for actuators required.

Measure	Cost (best estimate)	Cost (lower estimate)	Cost (upper estimate)	in year	Source / justification
PSI	€30	€20	€40	2020	TRL expert panel estimate under consideration of industry input, provided for other light vehicles (M1), for cost of making vehicle compliant with UN Regulation No. 135, which do not meet the requirements yet.
REV	€40	€25	€55	2012	(Seidl, et al., 2017) under consideration of industry input provided for other light vehicles (M1). Cost of a camera-based system using an existing display.
TPM	€5	€4	€10	2013	(van Zyl, van Goethem, Kanarachos, Rexeis, Hausberger, & Smokers, 2013) and (Seidl, et al., 2017). Cost of an indirect TPM solution fitted to vehicles with four wheels (no twin-wheels).

Table 53: Initial cost at mandatory introduction of proposed measures for N2&N3 vehicles. Cost estimate in € per vehicle equipped for the given year (subject to inflation). Estimated development and fixed production costs are included and spread equally across vehicles.

Measure	Cost (best estimate)	Cost (lower estimate)	Cost (upper estimate)	in year	Source / justification
ALC	€4	€2	€6	2020	(Seidl, et al., 2017) under consideration of industry input. Cost of an alcohol interlock installation sheet. The cost for equipping any vehicles with alcohol interlocks, made possible by this measure would be carried by the drivers affected.
DDR-DAD	€20	€10	€50	2020	(Seidl, et al., 2017) under consideration of industry input. Cost of a system based on existing sensors, such as steering wheel input.
DDR-ADR	€165	€147	€225	2020	(Seidl, et al., 2017) under consideration of industry input. Cost of a system based on driver-facing sensor hardware, such as camera.
ESS	€2	€0	€4	2020	(Seidl, et al., 2017). Nominal cost for software-based system (validation and testing).
ISA-VOL	€110	€92	€124	2012	(Seidl, et al., 2017) under consideration of industry input.
REV	€150	€130	€250	2012	(Seidl, et al., 2017) under consideration of industry input. Cost of full system including camera and display.
TPM	€66	€56	€200	2013	(van Zyl, van Goethem, Kanarachos, Rexeis, Hausberger, & Smokers, 2013) and (Seidl, et al., 2017) under consideration of industry input. Cost of a direct TPM solution fitted to the towing vehicle only (no trailers).
VIS-DET	€300	€150	€500	2020	TRL expert panel estimate under consideration of industry input and (Martin, Knight, Hunt, O'Connell, Cuerden, & McCarthy, 2017). Cost of front and side vulnerable road user detection and warning (no auto braking)
VIS-DIV	€150	€100	€450	2020	TRL expert panel estimate under consideration of industry input. Cost for best-in-class approach, i.e. adjustments of existing cabs. Requirement only applies to new types of vehicles, i.e. any cost incurred will partially be absorbed in cab re-design for new vehicle generation (no redesign cost for existing models). This is reflected in a cost estimate reflecting the lower end of estimates from industry input.

Annex 1.9 Appendices of results

Annex 1.9.1 Casualty baseline

Table 54: Casualty baseline (PO0, reflecting continued dispersion of existing mandatory safety measures and voluntary uptake of safety measures), EU-28 casualties per annum

Year	Best estimate		
	Fatal casualties	Serious casualties	Slight casualties
2017	25,245	244,674	1,200,609
2018	25,123	244,081	1,197,141
2019	25,012	243,387	1,192,776
2020	24,895	242,524	1,187,341
2021	24,759	241,495	1,181,155
2022	24,613	240,377	1,174,802
2023	24,459	239,198	1,168,456
2024	24,301	237,992	1,162,231
2025	24,141	236,787	1,156,208
2026	23,971	235,549	1,150,094
2027	23,788	234,239	1,143,662
2028	23,598	232,874	1,137,101
2029	23,408	231,496	1,130,854
2030	23,222	230,197	1,125,625
2031	23,044	229,002	1,121,229
2032	22,876	227,873	1,117,078
2033	22,721	226,850	1,113,449
2034	22,579	225,930	1,110,322
2035	22,451	225,114	1,107,619
2036	22,340	224,434	1,105,474

Year	Best estimate		
	Fatal casualties	Serious casualties	Slight casualties
2037	22,243	223,865	1,103,725

Annex 1.9.2 Monetary benefits and costs

Table 55: Benefits of policy option PO1 compared to the baseline scenario per vehicle category per year (future monetary value, best estimate)

Benefits PO1	M1	M2&M3	N1	N2&N3
2021	€ 0	€ 0	€ 0	€ 0
2022	€ 3,652,196	€ 854	€ 210,718	€ 966
2023	€ 151,296,385	€ 35,500	€ 9,203,539	€ 37,192
2024	€ 545,168,688	€ 133,426	€ 34,170,855	€ 145,379
2025	€ 1,000,898,311	€ 255,849	€ 64,560,479	€ 285,993
2026	€ 1,400,107,873	€ 371,047	€ 91,097,341	€ 415,470
2027	€ 1,771,664,008	€ 483,150	€ 114,072,703	€ 533,452
2028	€ 2,118,023,710	€ 592,081	€ 134,088,757	€ 641,286
2029	€ 2,445,305,073	€ 697,999	€ 151,755,745	€ 740,125
2030	€ 2,757,870,573	€ 801,080	€ 167,505,333	€ 830,859
2031	€ 3,037,253,906	€ 897,348	€ 181,520,552	€ 914,852
2032	€ 3,273,637,576	€ 983,998	€ 194,450,377	€ 994,352
2033	€ 3,480,530,155	€ 1,062,392	€ 206,230,741	€ 1,070,533
2034	€ 3,661,231,359	€ 1,132,949	€ 216,896,377	€ 1,143,570
2035	€ 3,818,311,956	€ 1,196,280	€ 226,553,732	€ 1,213,646
2036	€ 3,964,331,864	€ 1,254,962	€ 235,592,427	€ 1,279,173
2037	€ 4,104,957,655	€ 1,311,279	€ 239,408,474	€ 1,338,221

Table 56: Costs of policy option PO1 compared to the baseline scenario per vehicle category per year (future monetary value, best estimate)

Costs PO1	M1	M2&M3	N1	N2&N3
2021	€ 0	€ 0	€ 0	€ 0
2022	€ 20,851,089	€ 3,029	€ 2,052,932	€ 22,887
2023	€ 666,628,005	€ 103,749	€ 69,015,529	€ 832,924
2024	€ 1,096,450,305	€ 181,071	€ 120,557,163	€ 1,541,724
2025	€ 962,402,461	€ 174,006	€ 112,143,632	€ 1,568,627
2026	€ 950,204,101	€ 175,225	€ 104,096,560	€ 1,521,154
2027	€ 932,402,875	€ 176,448	€ 96,273,637	€ 1,476,343
2028	€ 918,897,205	€ 177,609	€ 89,786,569	€ 1,433,454
2029	€ 914,885,110	€ 178,677	€ 85,032,330	€ 1,392,087
2030	€ 920,097,355	€ 179,638	€ 81,758,624	€ 1,352,020
2031	€ 866,858,578	€ 171,522	€ 78,805,841	€ 1,361,456
2032	€ 821,028,128	€ 163,679	€ 76,508,761	€ 1,369,900
2033	€ 779,785,286	€ 156,099	€ 74,590,851	€ 1,377,368
2034	€ 741,519,077	€ 148,771	€ 72,890,548	€ 1,383,888
2035	€ 705,351,992	€ 141,687	€ 71,318,764	€ 1,389,492
2036	€ 706,705,939	€ 142,780	€ 70,636,578	€ 1,337,121
2037	€ 707,857,856	€ 143,761	€ 69,974,289	€ 1,286,365

Table 57: Benefits of policy option PO2 compared to the baseline scenario per vehicle category per year (future monetary value, best estimate)

Benefits PO2	M1	M2&M3	N1	N2&N3
2021	€ 0	€ 0	€ 0	€ 0
2022	€ 5,043,429	€ 58,327	€ 236,837	€ 241,474
2023	€ 210,270,736	€ 2,634,930	€ 10,319,870	€ 11,365,243
2024	€ 754,955,557	€ 9,825,649	€ 38,416,358	€ 43,208,350
2025	€ 1,406,209,021	€ 18,777,585	€ 74,799,102	€ 84,051,066
2026	€ 2,033,698,335	€ 27,228,953	€ 109,948,213	€ 122,090,314
2027	€ 2,648,095,042	€ 35,336,633	€ 140,958,380	€ 156,508,065
2028	€ 3,219,130,259	€ 43,067,457	€ 166,751,229	€ 187,606,327
2029	€ 3,753,286,844	€ 50,597,095	€ 188,508,110	€ 215,851,332
2030	€ 4,259,317,555	€ 58,111,280	€ 207,158,331	€ 243,081,828
2031	€ 4,706,545,364	€ 65,333,713	€ 223,294,324	€ 268,235,450
2032	€ 5,078,380,771	€ 71,876,058	€ 238,184,903	€ 292,288,513
2033	€ 5,396,376,447	€ 77,630,018	€ 251,521,779	€ 315,504,968
2034	€ 5,667,224,301	€ 82,575,411	€ 263,388,500	€ 337,632,315
2035	€ 5,896,416,783	€ 86,758,175	€ 274,092,181	€ 358,724,627
2036	€ 6,103,661,312	€ 90,376,170	€ 284,143,468	€ 378,248,366
2037	€ 6,297,613,219	€ 93,562,470	€ 288,550,553	€ 395,547,577

Table 58: Costs of policy option PO2 compared to the baseline scenario per vehicle category per year (future monetary value, best estimate)

Costs PO2	M1	M2&M3	N1	N2&N3
2021	€ 0	€ 0	€ 0	€ 0
2022	€ 36,608,027	€ 294,132	€ 2,187,630	€ 2,222,375
2023	€ 1,173,837,465	€ 10,287,194	€ 73,476,170	€ 82,588,682
2024	€ 1,946,885,861	€ 17,869,262	€ 129,257,128	€ 152,147,319
2025	€ 1,831,696,972	€ 17,226,074	€ 149,251,181	€ 155,289,935
2026	€ 1,968,686,605	€ 17,424,317	€ 170,685,530	€ 151,263,075
2027	€ 1,970,382,148	€ 17,351,814	€ 161,024,412	€ 145,183,480
2028	€ 1,981,486,293	€ 17,535,211	€ 153,190,295	€ 141,524,065
2029	€ 2,004,601,027	€ 18,181,667	€ 147,380,027	€ 141,654,506
2030	€ 2,037,673,215	€ 19,354,195	€ 143,213,366	€ 145,666,632
2031	€ 1,932,164,962	€ 19,538,819	€ 138,927,979	€ 155,089,405
2032	€ 1,836,698,195	€ 19,240,903	€ 135,370,212	€ 161,035,027
2033	€ 1,747,920,951	€ 18,583,567	€ 132,240,431	€ 163,975,882
2034	€ 1,663,929,128	€ 17,829,579	€ 129,364,756	€ 165,853,663
2035	€ 1,583,675,055	€ 16,977,921	€ 126,647,479	€ 166,498,652
2036	€ 1,587,193,701	€ 17,107,512	€ 125,473,959	€ 160,209,742
2037	€ 1,590,033,775	€ 17,224,227	€ 124,317,325	€ 154,121,562

Table 59: Benefits of policy option PO3 compared to the baseline scenario per vehicle category per year (future monetary value, best estimate)

Benefits PO3	M1	M2&M3	N1	N2&N3
2021	€ 0	€ 0	€ 0	€ 0
2022	€ 5,296,049	€ 64,080	€ 267,361	€ 262,633
2023	€ 220,849,893	€ 2,896,213	€ 11,704,789	€ 12,375,282
2024	€ 794,090,313	€ 10,806,181	€ 43,611,477	€ 47,111,746
2025	€ 1,496,571,707	€ 20,826,921	€ 87,490,526	€ 93,633,844
2026	€ 2,204,354,042	€ 30,619,015	€ 134,640,508	€ 140,563,460
2027	€ 2,910,930,151	€ 40,181,364	€ 178,777,729	€ 184,717,893
2028	€ 3,568,592,789	€ 49,310,690	€ 216,127,851	€ 224,526,483
2029	€ 4,183,755,428	€ 58,182,496	€ 248,035,142	€ 260,548,408
2030	€ 4,765,255,593	€ 66,984,433	€ 275,546,462	€ 294,681,257
2031	€ 5,277,941,509	€ 75,393,916	€ 299,305,818	€ 326,140,295
2032	€ 5,703,014,983	€ 82,991,402	€ 320,661,884	€ 355,962,675
2033	€ 6,064,831,386	€ 89,687,075	€ 339,457,416	€ 384,478,601
2034	€ 6,371,420,680	€ 95,468,181	€ 355,889,709	€ 411,581,971
2035	€ 6,629,391,751	€ 100,391,933	€ 370,396,600	€ 437,312,718
2036	€ 6,861,170,981	€ 104,689,595	€ 383,714,462	€ 461,074,546
2037	€ 7,076,868,299	€ 108,522,074	€ 390,972,196	€ 482,050,865

Table 60: Costs of policy option PO3 compared to the baseline scenario per vehicle category per year (future monetary value, best estimate)

Costs PO3	M1	M2&M3	N1	N2&N3
2021	€ 0	€ 0	€ 0	€ 0
2022	€ 42,192,710	€ 423,552	€ 5,964,756	€ 3,415,339
2023	€ 1,353,540,595	€ 14,823,967	€ 205,725,210	€ 127,023,221
2024	€ 2,261,052,623	€ 25,820,055	€ 364,708,363	€ 234,596,848
2025	€ 2,672,896,381	€ 28,071,684	€ 454,925,311	€ 268,124,075
2026	€ 3,435,357,794	€ 31,645,012	€ 549,369,467	€ 289,349,543
2027	€ 3,492,303,600	€ 31,685,993	€ 535,330,457	€ 279,335,838
2028	€ 3,555,792,162	€ 31,971,352	€ 523,206,307	€ 271,847,808
2029	€ 3,628,433,359	€ 32,708,691	€ 513,156,649	€ 268,252,408
2030	€ 3,708,222,578	€ 33,961,455	€ 504,782,127	€ 268,638,814
2031	€ 3,527,235,174	€ 33,487,203	€ 493,196,216	€ 278,929,380
2032	€ 3,358,790,944	€ 32,552,048	€ 482,490,434	€ 285,648,055
2033	€ 3,199,454,280	€ 31,278,482	€ 472,359,156	€ 289,270,906
2034	€ 3,047,245,254	€ 29,928,662	€ 462,624,055	€ 291,743,199
2035	€ 2,901,045,223	€ 28,500,980	€ 453,185,807	€ 292,898,673
2036	€ 2,907,900,432	€ 28,719,539	€ 449,132,708	€ 281,846,047
2037	€ 2,913,320,014	€ 28,916,012	€ 445,068,893	€ 271,140,899

Annex 1.9.3 Casualties prevented

Table 61: Fatal casualties prevented across EU-28 by safety measures of policy option PO1 compared to the baseline scenario per vehicle category per year (best estimate)

Fatal casualties PO1	M1	M2&M3	N1	N2&N3
2021	0	0	0	0
2022	1	0	0	0
2023	47	0	3	0
2024	172	0	11	0
2025	321	0	21	0
2026	457	0	30	0
2027	589	0	38	0
2028	717	0	47	0
2029	843	0	53	0
2030	969	0	61	0
2031	1,087	0	67	0
2032	1,195	0	73	0
2033	1,295	1	79	0
2034	1,390	0	84	0
2035	1,479	0	90	0
2036	1,567	1	96	0
2037	1,656	0	99	0

Table 62: Serious casualties prevented across EU-28 by safety measures of policy option PO1 compared to the baseline scenario per vehicle category per year (best estimate)

Serious casualties PO1	M1	M2&M3	N1	N2&N3
2021	0	0	0	0
2022	5	0	0	0
2023	205	1	13	0
2024	757	0	51	1
2025	1,423	0	98	1
2026	2,041	1	141	2
2027	2,648	2	180	2
2028	3,245	2	217	2
2029	3,837	1	251	3
2030	4,431	2	285	3
2031	4,995	3	315	4
2032	5,509	3	348	4
2033	5,995	3	379	4
2034	6,454	3	408	4
2035	6,886	4	437	5
2036	7,314	4	466	6
2037	7,748	4	485	6

Table 63: Slight casualties prevented across EU-28 by safety measures of policy option PO1 compared to the baseline scenario per vehicle category per year (best estimate)

Slight casualties PO1	M1	M2&M3	N1	N2&N3
2021	0	0	0	0
2022	20	0	1	0
2023	836	0	36	0
2024	3,107	1	138	2
2025	5,883	2	267	4
2026	8,491	4	386	5
2027	11,103	4	498	7
2028	13,718	5	601	8
2029	16,359	7	697	9
2030	19,051	8	790	10
2031	21,650	8	878	12
2032	24,051	10	961	13
2033	26,323	11	1,042	15
2034	28,482	12	1,120	16
2035	30,533	13	1,196	18
2036	32,569	14	1,273	18
2037	34,639	14	1,324	20

Table 64: Fatal casualties prevented across EU-28 by safety measures of policy option PO2 compared to the baseline scenario per vehicle category per year (best estimate)

Fatal casualties PO2	M1	M2&M3	N1	N2&N3
2021	0	0	0	0
2022	1	0	0	0
2023	65	0	4	5
2024	237	2	12	17
2025	446	4	24	34
2026	651	5	35	51
2027	855	8	46	67
2028	1,054	10	56	82
2029	1,245	11	64	98
2030	1,434	14	72	112
2031	1,608	16	80	127
2032	1,762	18	86	141
2033	1,903	20	94	155
2034	2,032	22	99	171
2035	2,150	24	105	185
2036	2,263	26	112	199
2037	2,375	27	116	214

Table 65: Serious casualties prevented across EU-28 by safety measures of policy option PO2 compared to the baseline scenario per vehicle category per year (best estimate)

Serious casualties PO2	M1	M2&M3	N1	N2&N3
2021	0	0	0	0
2022	7	1	0	0
2023	294	6	14	11
2024	1,084	21	57	45
2025	2,089	41	115	87
2026	3,149	61	175	128
2027	4,260	81	231	165
2028	5,355	101	280	197
2029	6,441	120	323	229
2030	7,530	141	362	264
2031	8,562	162	397	298
2032	9,497	181	435	330
2033	10,371	199	471	362
2034	11,186	215	505	395
2035	11,948	231	538	428
2036	12,695	245	571	460
2037	13,445	258	594	489

Table 66: Slight casualties prevented across EU-28 by safety measures of policy option PO2 compared to the baseline scenario per vehicle category per year (best estimate)

Slight casualties PO2	M1	M2&M3	N1	N2&N3
2021	0	0	0	0
2022	25	0	1	0
2023	1,064	18	43	26
2024	3,946	67	165	101
2025	7,580	131	332	202
2026	11,275	195	509	301
2027	15,125	257	682	398
2028	18,971	319	837	490
2029	22,849	382	979	580
2030	26,801	446	1,111	667
2031	30,610	509	1,235	753
2032	34,120	568	1,350	839
2033	37,430	620	1,459	927
2034	40,561	668	1,563	1,013
2035	43,525	710	1,664	1,100
2036	46,454	748	1,766	1,185
2037	49,420	783	1,840	1,267

Table 67: Fatal casualties prevented across EU-28 by safety measures of policy option PO3 compared to the baseline scenario per vehicle category per year (best estimate)

Fatal casualties PO3	M1	M2&M3	N1	N2&N3
2021	0	0	0	0
2022	1	0	0	0
2023	66	0	4	5
2024	242	2	13	18
2025	460	4	27	37
2026	680	6	42	58
2027	902	9	56	78
2028	1,118	11	70	96
2029	1,325	13	81	115
2030	1,529	15	93	132
2031	1,716	17	103	149
2032	1,880	20	112	166
2033	2,030	22	121	184
2034	2,166	24	129	202
2035	2,290	26	137	219
2036	2,408	28	145	236
2037	2,524	30	150	252

Table 68: Serious casualties prevented across EU-28 by safety measures of policy option PO3 compared to the baseline scenario per vehicle category per year (best estimate)

Serious casualties PO3	M1	M2&M3	N1	N2&N3
2021	0	0	0	0
2022	8	1	1	0
2023	320	7	17	13
2024	1,180	23	67	50
2025	2,306	46	138	100
2026	3,553	70	221	153
2027	4,887	93	301	205
2028	6,204	117	373	250
2029	7,513	140	436	295
2030	8,822	165	495	342
2031	10,061	189	548	387
2032	11,182	212	602	431
2033	12,225	233	653	474
2034	13,195	252	701	517
2035	14,097	270	746	561
2036	14,978	288	792	603
2037	15,859	304	826	642

Table 69: Slight casualties prevented across EU-28 by safety measures of policy option PO3 compared to the baseline scenario per vehicle category per year (best estimate)

Slight casualties PO3	M1	M2&M3	N1	N2&N3
2021	0	0	0	0
2022	28	0	2	1
2023	1,173	19	52	28
2024	4,360	73	201	111
2025	8,514	146	420	231
2026	13,002	227	682	367
2027	17,798	310	953	507
2028	22,597	393	1,203	641
2029	27,435	478	1,436	771
2030	32,359	563	1,657	897
2031	37,099	647	1,866	1,020
2032	41,454	726	2,061	1,143
2033	45,548	798	2,248	1,267
2034	49,410	863	2,426	1,390
2035	53,053	923	2,599	1,514
2036	56,645	978	2,771	1,635
2037	60,272	1,030	2,909	1,751

Annex 1.9.4 Sensitivity analysis

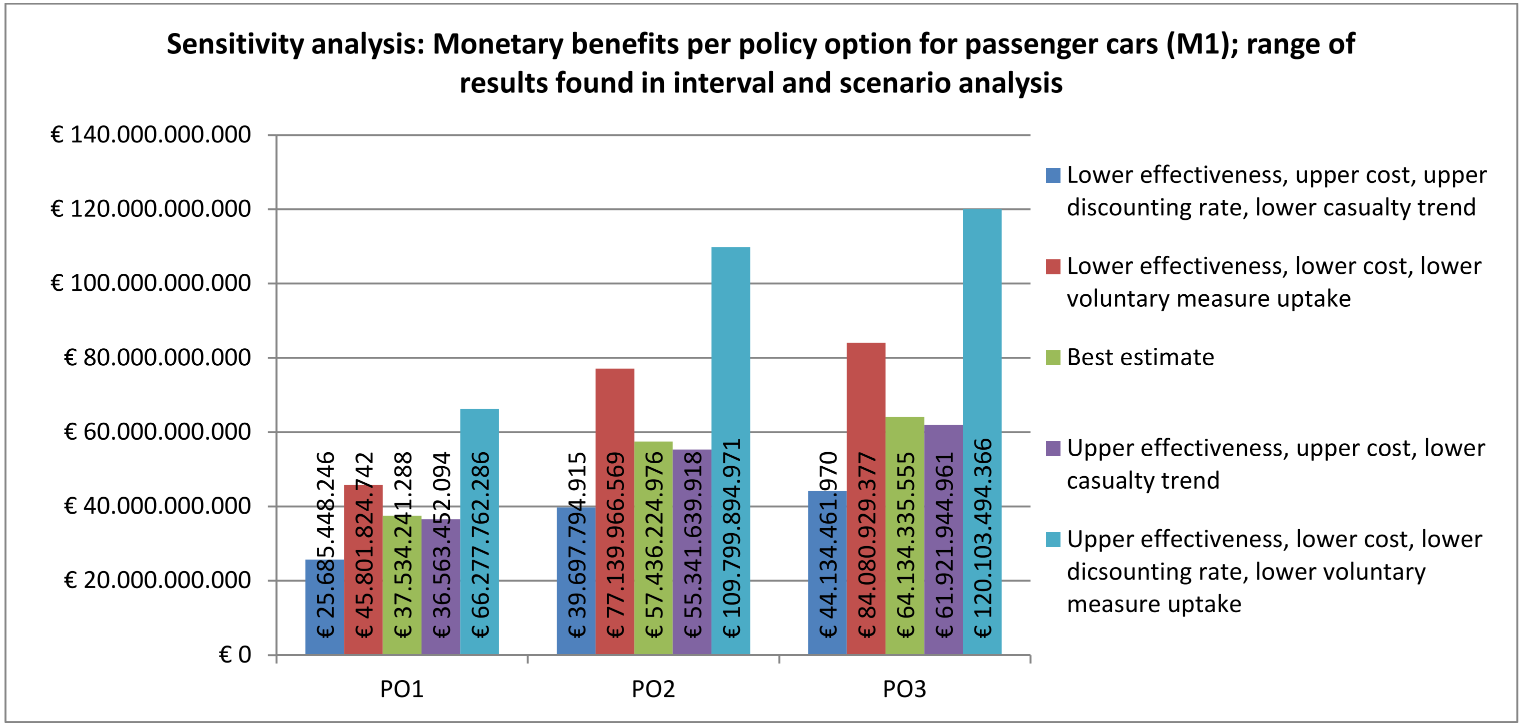

Figure 29: Passenger cars (M1): Present monetary value of benefits of M1 safety measures over entire evaluation period 2021–2037 compared to the baseline scenario (range of results found in interval and scenario analysis)

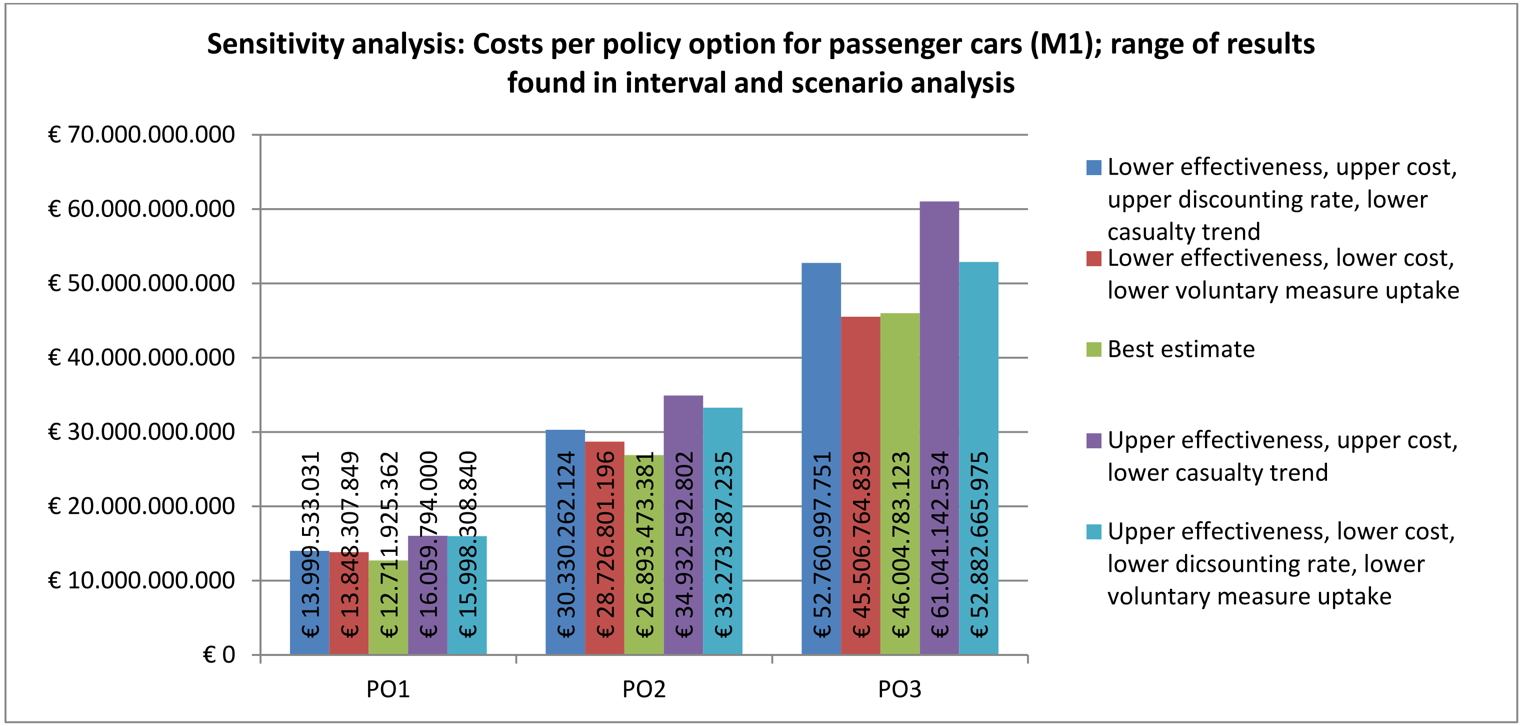

Figure 30: Passenger cars (M1): Present value of costs of M1 safety measures over entire evaluation period 2021–2037 compared to the baseline scenario (range of results found in interval and scenario analysis)

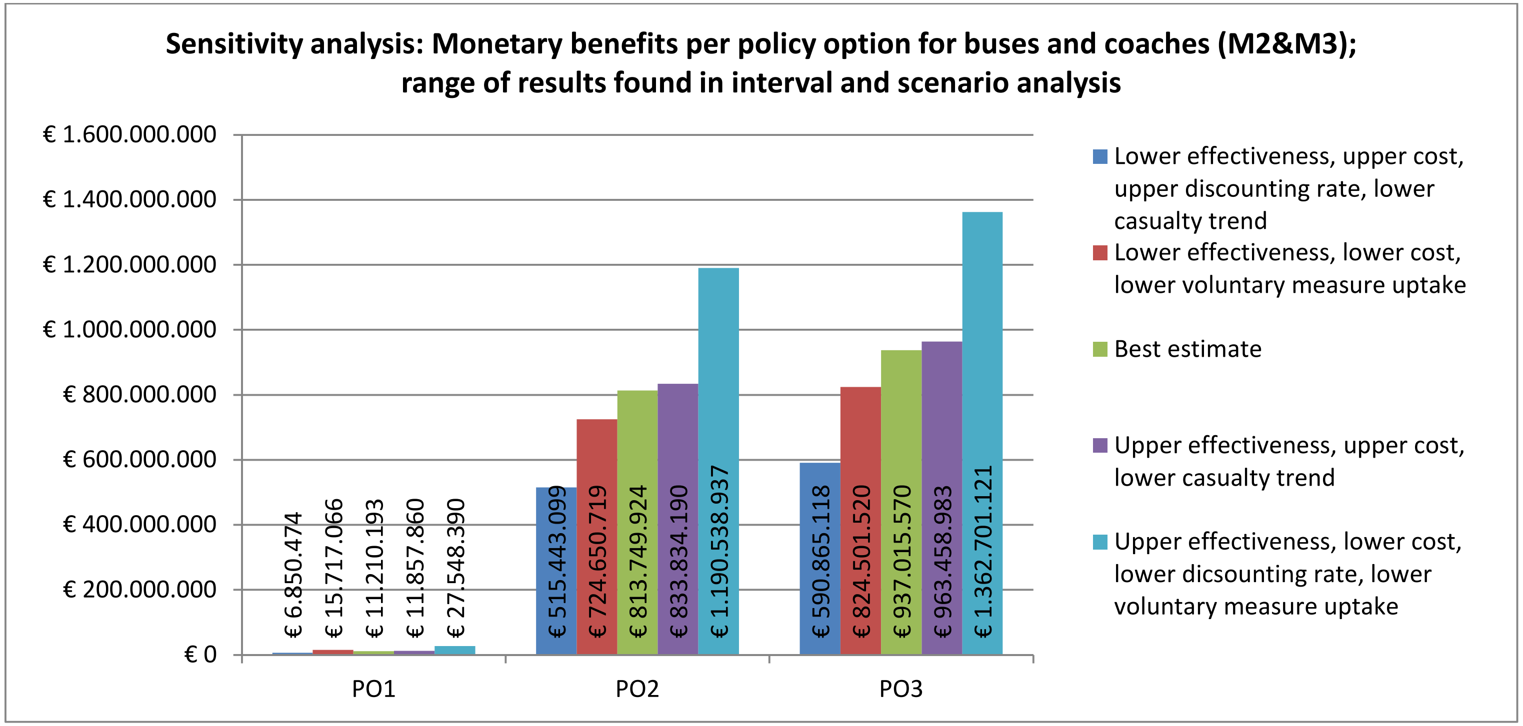

Figure 31: Buses and coaches (M2&M3): Present monetary value of benefits of M2&M3 safety measures over entire evaluation period 2021–2037 compared to the baseline scenario (range of results found in interval and scenario analysis)

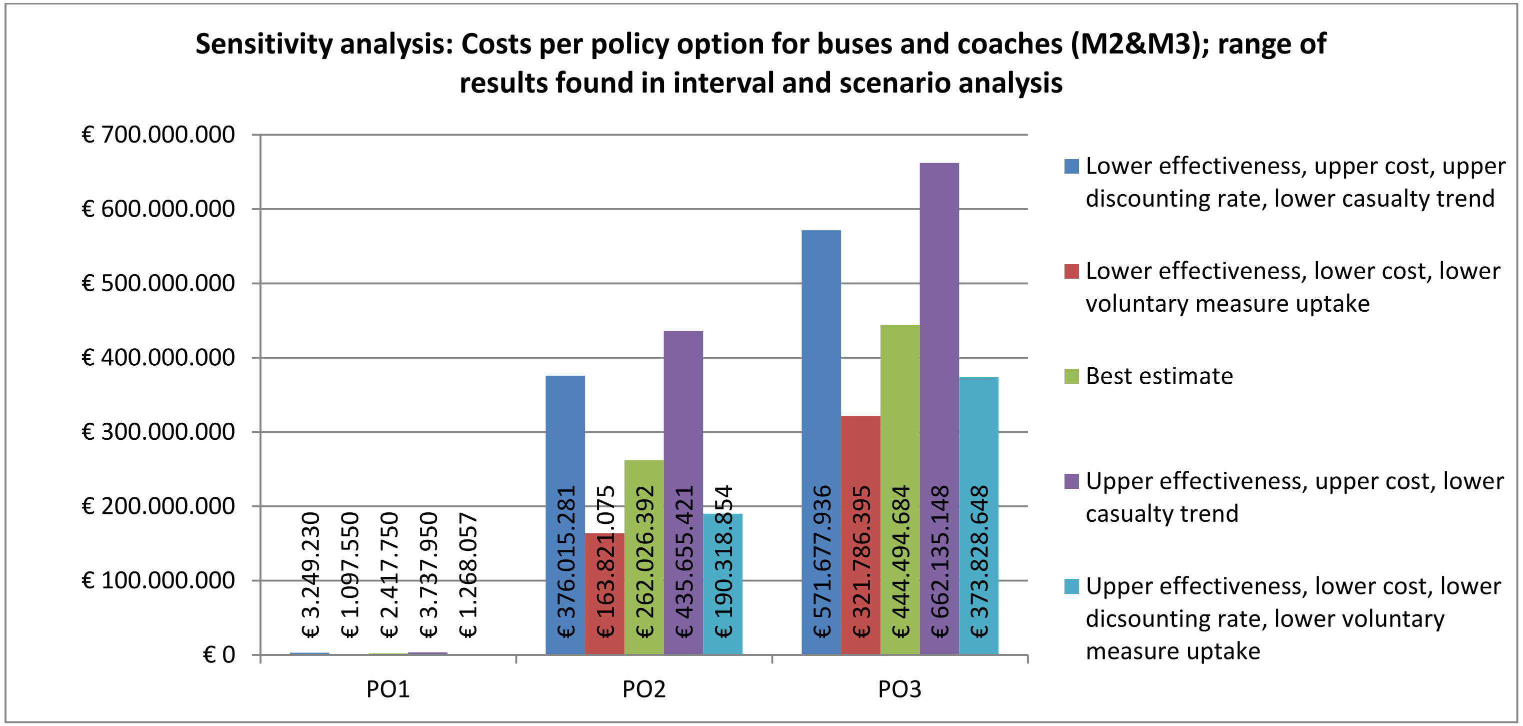

Figure 32: Buses and coaches (M2&M3): Present value of costs of M2&M3 safety measures over entire evaluation period 2021–2037 compared to the baseline scenario (range of results found in interval and scenario analysis)

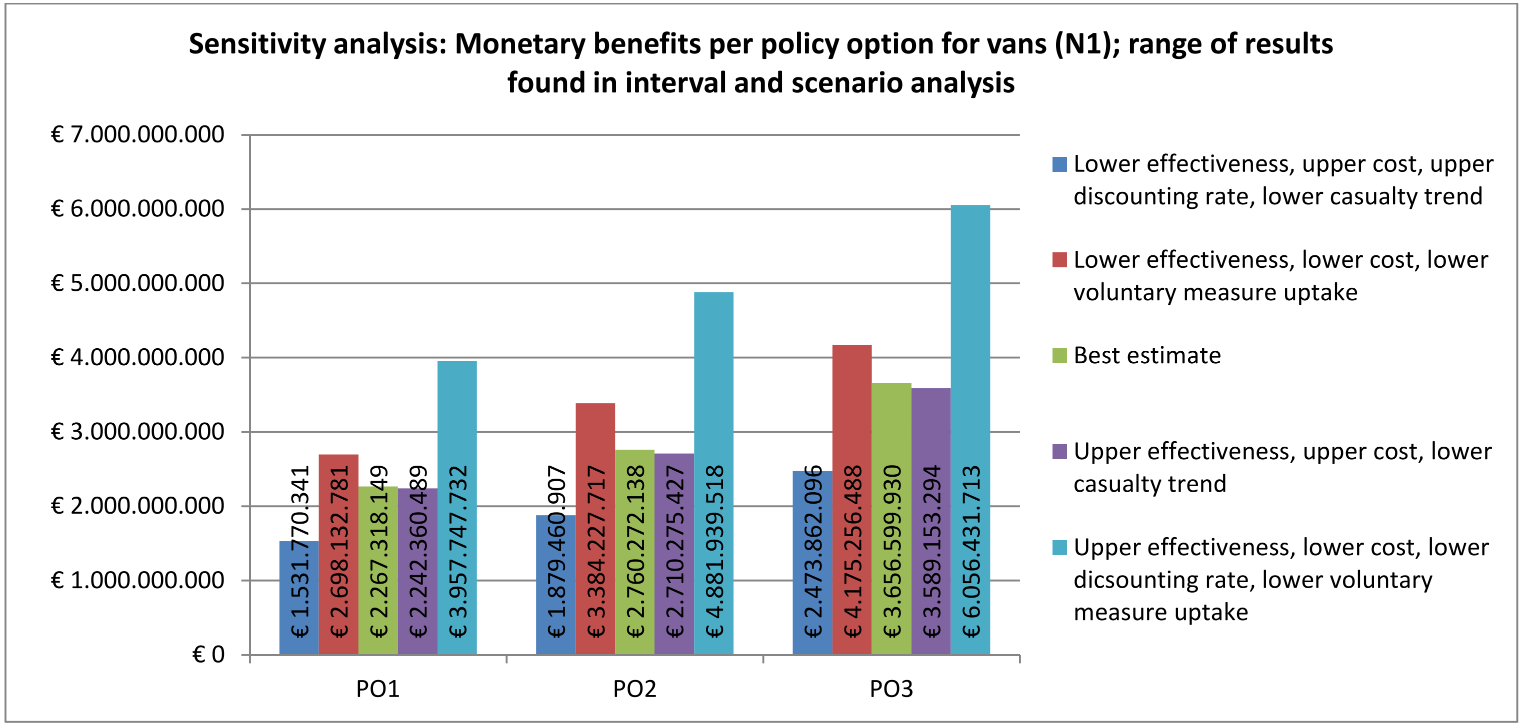

Figure 33: Vans (N1): Present monetary value of benefits of N1 safety measures over entire evaluation period 2021–2037 compared to the baseline scenario (range of results found in interval and scenario analysis)

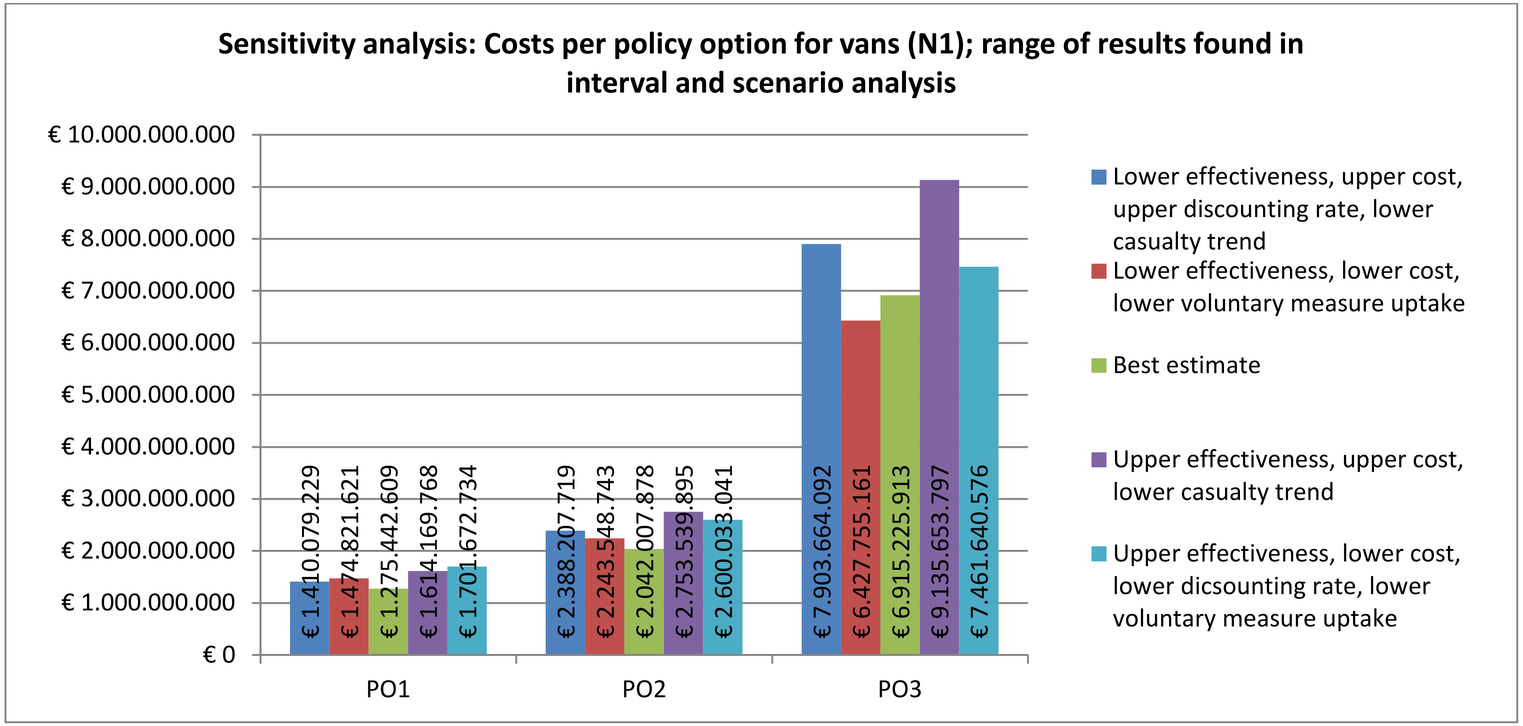

Figure 34: Vans (N1): Present value of costs of N1 safety measures over entire evaluation period 2021–2037 compared to the baseline scenario (range of results found in interval and scenario analysis)

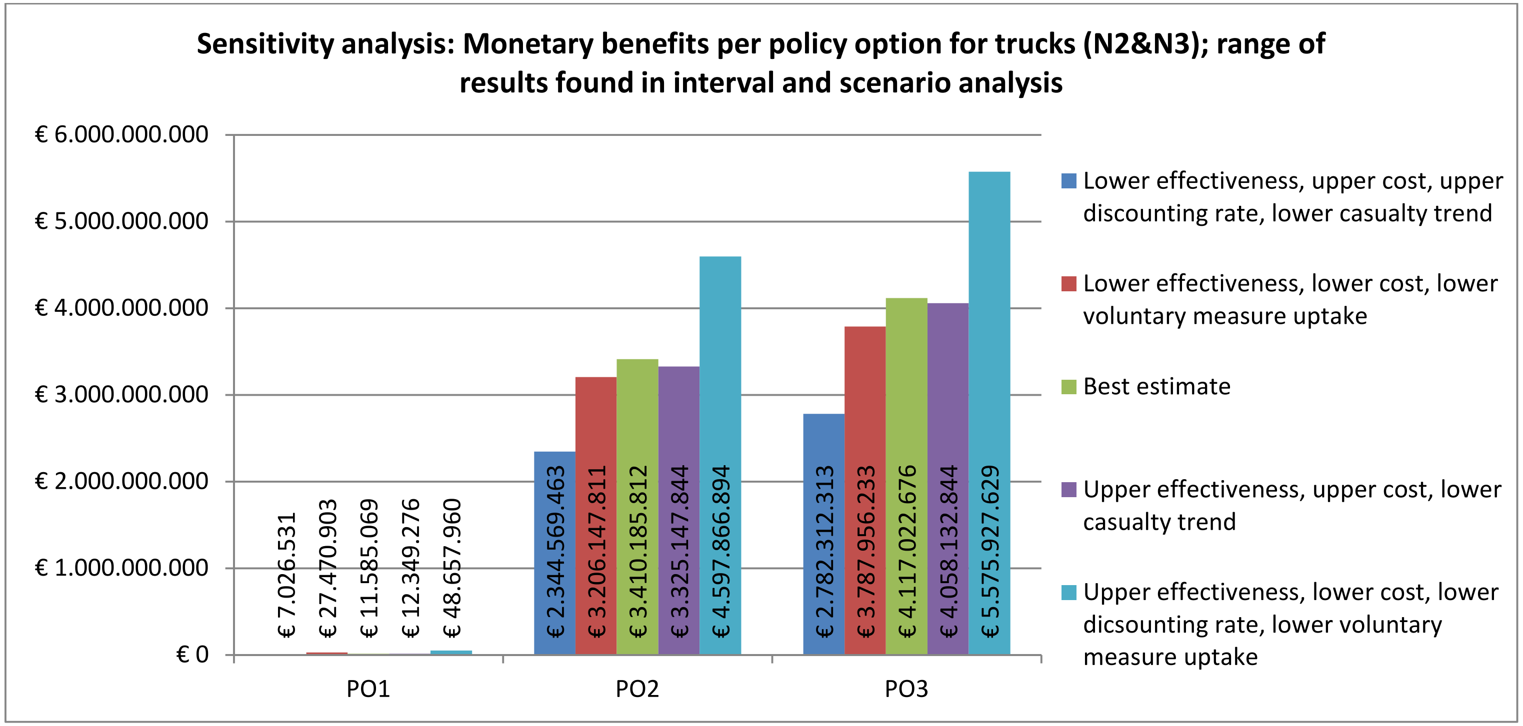

Figure 35: Trucks (N2&N3): Present monetary value of benefits of N2&N3 safety measures over entire evaluation period 2021–2037 compared to the baseline scenario (range of results found in interval and scenario analysis)

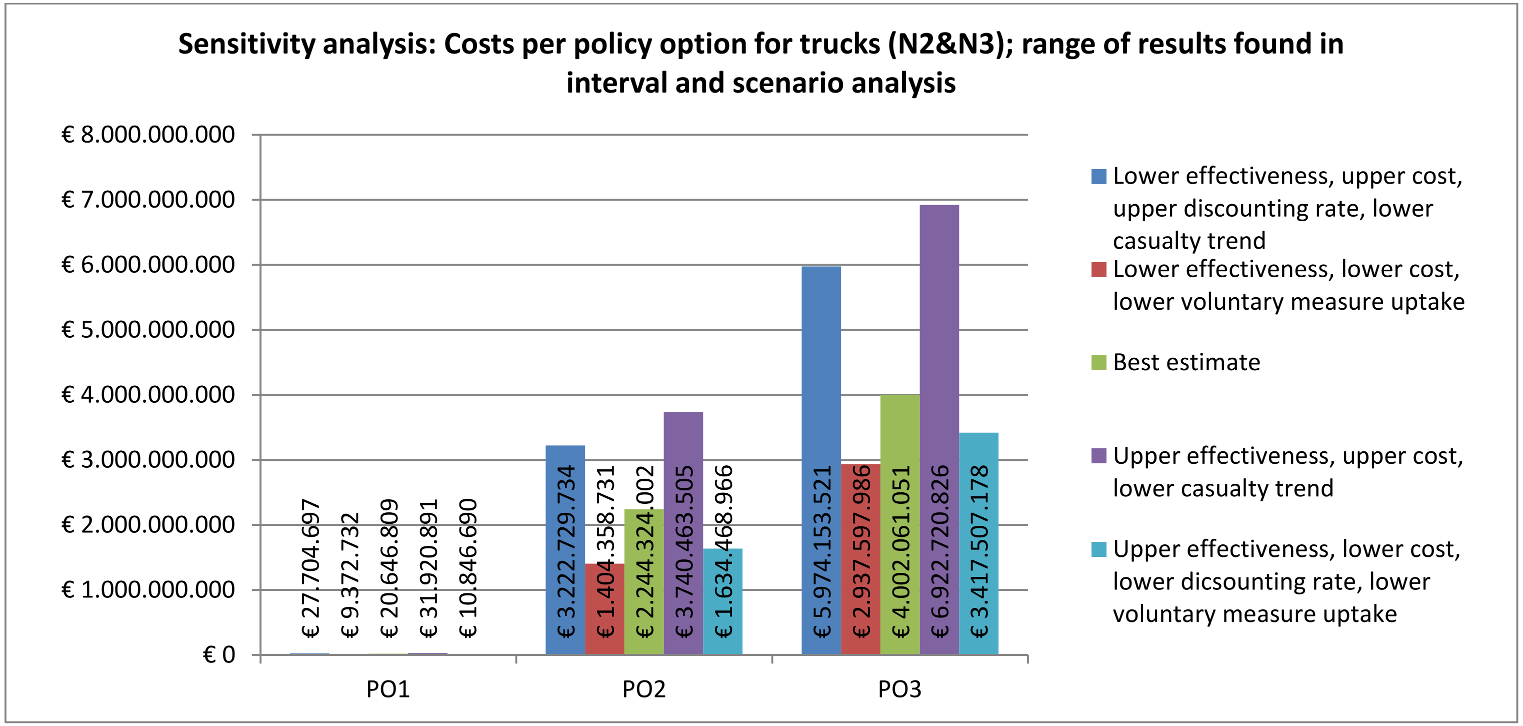

Figure 36: Trucks (N2&N3): Present value of costs of N2&N3 safety measures over entire evaluation period 2021–2037 compared to the baseline scenario (range of results found in interval and scenario analysis)

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