Study on the feasibility, costs and benefits of retrofitting advanced driver assistance to improve road safety

Final Report
Study on the feasibility, costs and benefits of retrofitting advanced driver assistance to improve road safety

Final Report
Europe Direct is a service to help you find answers to your questions about the European Union.

Freephone number (*):

00 800 6 7 8 9 10 11

(*) The information given is free, as are most calls (though some operators, phone boxes or hotels may charge you).

LEGAL NOTICE
This document has been prepared for the European Commission however it reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.


doi:10.2832/316686

© European Union, 2020
Reproduction is authorised provided the source is acknowledged.
Study on the feasibility, costs and benefits of retrofitting ADAS to improve road safety

TABLE OF CONTENTS

TABLE OF CONTENTS .................................................................................................................. 5
ABBREVIATIONS .......................................................................................................................... 7
TERMS USED .................................................................................................................................. 8
ABSTRACT ......................................................................................................................................... 9
EXECUTIVE SUMMARY ............................................................................................................... 10
RÉSUMÉ EXÉCUTIF ....................................................................................................................... ERROR! BOOKMARK NOT DEFINED.
1 INTRODUCTION AND BACKGROUND ...................................................................................... 12
   1.1 Purpose of the document .................................................................................................... 12
   1.2 Objectives of the study .................................................................................................... 12
   1.3 Background: ADAS in General Safety Regulation update .................................................. 12
2 METHODOLOGY .......................................................................................................................... 14
   2.1 Technical feasibility .......................................................................................................... 14
   2.2 Assessment of benefits ..................................................................................................... 14
   2.3 Assessment of costs ......................................................................................................... 15
   2.4 Cost-benefit analysis ....................................................................................................... 16
   2.5 Stakeholder consultation ................................................................................................. 16
3 TECHNICAL FEASIBILITY OF RETROFITTING ADAS ................................................................. 18
   3.1 Interests in retrofitting ...................................................................................................... 18
   3.2 Main technical issue with ADAS retrofitting: access to in-vehicle resources ....................... 18
      3.2.1 Third-party access to in-vehicle data ......................................................................... 19
      3.2.2 Third-party access to in-vehicle display ..................................................................... 19
      3.2.3 Third-party access to in-vehicle actuators .................................................................. 20
      3.2.4 Conclusion ................................................................................................................. 20
   3.3 Selection of ADAS to the retrofit study .............................................................................. 20
      3.3.1 Retrofit ADAS, which are included in this study ......................................................... 21
      3.3.2 Retrofit ADAS, which are not included in this study ................................................. 24
      3.3.3 Safety measures which are out-of-scope .................................................................... 25
      3.3.4 Overview .................................................................................................................. 25
   3.4 Retrofit ADAS Performance and Installation ..................................................................... 26
      3.4.1 Retrofit ADAS Performance ..................................................................................... 26
      3.4.2 Suitability of ADAS retrofitting for vehicle fleet ......................................................... 28
   3.5 Summary of retrofit ADAS technical feasibility ................................................................. 28
   3.6 Overview of retrofit systems on the market ........................................................................ 31
4 BASELINE SCENARIO ................................................................................................................... 33
   4.1 Methodology ..................................................................................................................... 33
   4.2 Development of the EU fleet ............................................................................................. 33
   4.3 Penetration rate for factory-fitted ADAS ........................................................................... 35
   4.4 Autonomous development of retrofit ADAS in the vehicle fleet ....................................... 36
      4.4.1 Current penetration of retrofit ADAS .......................................................................... 36
      4.4.2 Awareness raising measures ....................................................................................... 36
      4.4.3 Financial incentives .................................................................................................... 37
      4.4.4 Insurance policies (or insurance premiums) ............................................................... 38
      4.4.5 Public procurement requirements ............................................................................... 39
      4.4.6 Urban vehicle access regulations (UVAR) ................................................................. 39
      4.4.7 Conclusion on autonomous development of retrofitting .......................................... 41
   4.5 Availability of single ADAS-functionality retrofit products ............................................... 41
   4.6 Conclusions ....................................................................................................................... 42
5 MEASURES STIMULATING UPTAKE OF RETROFITTING ........................................ 44
  5.1 Voluntary measures (PO1) ....................................................................... 44
  5.2 Mandatory measures (PO2) .................................................................... 45
  5.3 Exemptions ............................................................................................. 46
  5.4 Effects on the penetration rate ............................................................... 46
6 COST-BENEFIT ANALYSIS ............................................................................ 48
  6.1 Evaluation period, discount rate and presentation of results ....................... 48
  6.2 Costs .......................................................................................................... 48
    6.2.1 Initial purchase and installation costs .................................................. 49
    6.2.2 Maintenance, inspection and repair costs .......................................... 50
    6.2.3 Campaign costs .................................................................................. 54
    6.2.4 Subsidy costs ...................................................................................... 54
    6.2.5 Other non-quantifiable costs .............................................................. 55
  6.3 Benefits of ADAS retrofitting .................................................................... 56
    6.3.1 Description of safety benefits (direct and indirect) ............................... 57
    6.3.2 Estimates on effectiveness based on earlier studies ............................ 59
    6.3.3 Estimation of safety potential .............................................................. 63
    6.3.4 Correcting for a penetration rate above zero ...................................... 67
    6.3.5 Number of prevented casualties ......................................................... 67
    6.3.6 Assessment of the target population ................................................... 68
    6.3.7 Functioning of the model ................................................................... 68
    6.3.8 Monetization of casualties prevented ............................................... 69
  6.4 Results ......................................................................................................... 69
    6.4.1 CBA results ........................................................................................ 69
    6.4.2 Development of costs and benefits over time ..................................... 71
  6.5 Sensitivity analysis .................................................................................... 72
    6.5.1 Sensitivity Analysis 1 .......................................................................... 73
    6.5.2 Sensitivity Analysis 2 .......................................................................... 73
    6.5.3 Sensitivity Analysis 3 .......................................................................... 74
    6.5.4 Sensitivity Analysis 4 .......................................................................... 75
7 CONCLUSIONS AND RECOMMENDATIONS .................................................. 77
  7.1 Conclusions ............................................................................................... 77
    7.1.1 Technical feasibility ............................................................................ 77
    7.1.2 Baseline scenario ................................................................................ 77
    7.1.3 Stimulating measures to retrofit ADAS ............................................... 77
    7.1.4 Costs benefit analysis ......................................................................... 77
    7.1.5 Sensitivity analysis ............................................................................. 78
  7.2 Recommendations ...................................................................................... 78
REFERENCES ....................................................................................................... 79
ANNEX A: PENETRATION RATES ................................................................. 87
ANNEX B: PURCHASE AND INSTALLATION COSTS OF RETROFIT ADAS ........ 88
ANNEX C: ROAD SAFETY CAMPAIGNS ....................................................... 89
ANNEX D: BASELINE ASSESSMENT OF ROAD CASUALTIES ....................... 90
ANNEX E: ASSESSMENT OF CURRENT RETROFIT ADAS IN THE EU VEHICLE FLEET ...... 91
ANNEX F: COMPARISON BETWEEN ASSESSMENT METHODOLOGIES ............. 92
ANNEX G: SUMMARY OF THE STAKEHOLDER CONSULTATION ..................... 94
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>Anti-Lock Braking System</td>
</tr>
<tr>
<td>ADAS</td>
<td>Advanced Driver Assistance Systems</td>
</tr>
<tr>
<td>AEB¹</td>
<td>Advanced Emergency Braking</td>
</tr>
<tr>
<td>AEB-VEH</td>
<td>Advanced Emergency Braking for obstacles and moving vehicles ahead</td>
</tr>
<tr>
<td>AEB-PCD</td>
<td>Advanced Emergency Braking for pedestrians and cyclists</td>
</tr>
<tr>
<td>BCR</td>
<td>Benefit-to-Cost Ratio</td>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network</td>
</tr>
<tr>
<td>CARE</td>
<td>(EU) Community Roads Accidents Database</td>
</tr>
<tr>
<td>CBA</td>
<td>Cost-Benefit Analysis</td>
</tr>
<tr>
<td>DDR</td>
<td>Driver Distraction Recognition</td>
</tr>
<tr>
<td>DDR-DAD</td>
<td>Drowsiness and Attention warning</td>
</tr>
<tr>
<td>DDR-ADR</td>
<td>Advanced Driver Distraction warning</td>
</tr>
<tr>
<td>eCall</td>
<td>In-vehicle Emergency Call</td>
</tr>
<tr>
<td>ECU</td>
<td>Electronic Control Unit</td>
</tr>
<tr>
<td>EDR</td>
<td>Event (accident) Data Recorder</td>
</tr>
<tr>
<td>ESC</td>
<td>Electronic Stability Control</td>
</tr>
<tr>
<td>ESS</td>
<td>Emergency Stop Signal</td>
</tr>
<tr>
<td>FCW</td>
<td>Forward Collision Warning</td>
</tr>
<tr>
<td>FCW-VEH</td>
<td>Forward Collision Warning with vehicle detection capability</td>
</tr>
<tr>
<td>FCW-PCD</td>
<td>Forward Collision Warning with pedestrian and bicycle detection capability</td>
</tr>
<tr>
<td>FMS</td>
<td>Fleet Management Systems (interface)</td>
</tr>
<tr>
<td>GSR</td>
<td>General Safety Regulation (Regulation (EC) No 661/2009)</td>
</tr>
<tr>
<td>HDV</td>
<td>Heavy Duty Vehicle</td>
</tr>
<tr>
<td>HGV</td>
<td>Heavy Goods Vehicle</td>
</tr>
<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
</tr>
<tr>
<td>IRR</td>
<td>Internal Rate of Return</td>
</tr>
<tr>
<td>ISA</td>
<td>Intelligent Speed Adaptation</td>
</tr>
<tr>
<td>ISA-VOL</td>
<td>Voluntary Intelligent Speed Adaptation</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transport Systems</td>
</tr>
<tr>
<td>IVI</td>
<td>In-Vehicle Infotainment</td>
</tr>
<tr>
<td>LDW</td>
<td>Lane Departure Warning</td>
</tr>
<tr>
<td>LKA</td>
<td>Lane Keeping Assist</td>
</tr>
<tr>
<td>LKA-ELK</td>
<td>Emergency Lane-Keeper</td>
</tr>
<tr>
<td>MSD</td>
<td>Minimum Set of Data (for eCall)</td>
</tr>
<tr>
<td>OBD-II</td>
<td>On-Board Diagnostics (standard interface)</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>PSAP</td>
<td>Public Safety Answering Point</td>
</tr>
<tr>
<td>PTI</td>
<td>Periodic Technical Inspection</td>
</tr>
<tr>
<td>REV</td>
<td>Reversing detection system</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>SLI</td>
<td>Speed Limit Information</td>
</tr>
<tr>
<td>TPM</td>
<td>Tyre Pressure monitoring</td>
</tr>
<tr>
<td>UVAR</td>
<td>Urban vehicle access regulations</td>
</tr>
<tr>
<td>VAT</td>
<td>Value Added Tax</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>Vulnerable road user detection and warning on front and side of vehicle</td>
</tr>
</tbody>
</table>

¹ The acronyms used for ADAS in the report are the acronyms used in the impact assessment study for the GSR update proposal (European Commission, 2018c). The description is according to Regulation (EU) 2019/2144
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIS-DIV</td>
<td>Vulnerable road user improved direct vision from driver’s position</td>
</tr>
<tr>
<td>VRU</td>
<td>Vulnerable Road User: non-motorised road users, including, in particular, cyclists and pedestrians, as well as users of powered two-wheelers (Regulation (EU) 2019/2144)</td>
</tr>
</tbody>
</table>

**TERMS USED**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality</td>
<td>A set of functions associated with software or hardware.</td>
</tr>
<tr>
<td>GSR update</td>
<td>Regulation (EU) 2019/2144. This regulation is an update of the GSR (Regulation (EC) No 661/2009), and was adopted by the Council of the EU on 27 November 2019.</td>
</tr>
<tr>
<td>ADAS</td>
<td>Advanced Driver Assistance System. Within the framework of these study, safety systems included in Regulation (EU) 2019/2144, and in addition 112 eCall</td>
</tr>
<tr>
<td>retrofit ADAS</td>
<td>ADAS systems which can be installed in vehicles after purchase. Within the framework of this study, the systems selected for analysis (FCW, LDW, SLI, DDR-ADR, REV, TPM, VIS-DET, 112 eCall)</td>
</tr>
<tr>
<td>SWD/2018/190</td>
<td>Commission Working Staff document, Impact assessment performed for the proposal of the GSR (European Commission, 2018c)</td>
</tr>
</tbody>
</table>
ABSTRACT
The European Parliament has adopted regulation (EU) 2019/2144, which will make several ADAS (Advanced Driver Assistance System) mandatory in new models from June 2022 onward and in all new vehicles from June 2024 onwards. However, due to the slow renewal of the vehicle fleet, it will take several years before a meaningful portion of the fleet is equipped with these lifesaving systems. To compensate for this, the safety of existing vehicles could be improved with retrofit ADAS systems. The objective of this study is to assess the feasibility, costs and benefits of retrofitting ADAS.

This study examined the technical feasibility of various retrofit ADAS systems and assessed the following in greater detail: Forward Collision Warning, Lane Departure Warning, Advanced Driver Distraction Warning, Speed Limit Information, Reversing Detection, Tyre Pressure Monitoring system, Turn Assistant for trucks and 112 eCall.

The study examines the potential safety impacts of retrofitting the vehicle fleet and presents a cost-benefit assessment for the measures. This report addresses voluntarily installable measures as well as mandatory measures.
EXECUTIVE SUMMARY

Road fatalities have decreased substantially during the last decades, but in the last few years, the reduction rate has been slower than required to achieve the EU's road safety targets. ADAS (Advanced Driver Assistance Systems) have assisted in the reduction of accidents. Based on the initiative of the European Commission, the European Parliament and the Council of the EU have adopted Regulation (EU) 2019/2144 that will make several ADAS, such as Advanced Emergency Braking (AEB), Intelligent speed assistance (ISA) mandatory on new vehicles. The first wave of these systems will be mandatory in new models from June 2022 and in all new vehicles from June 2024.

As the average age of road vehicles in the European fleet is over 10 years, it will take approximately 10 years before most of the fleet is equipped with these lifesaving functions. The deployment of retrofit ADAS devices could perhaps speed up the uptake of these functions. The main objective of this study is to provide information on the technical feasibility, as well as costs and benefits, of retrofit ADAS for existing vehicles.

The study begins with an assessment of the technical feasibility of retrofitting ADAS, concentrating on the safety systems included in Regulation (EU) 2019/2144 and 112 eCall. Following this, the report describes the methodology for the calculation of the safety benefits and the CBA (in which the fleet's baseline condition is considered the starting point for the calculations). Next, an assessment of potential safety benefits of the ADAS measures is presented. Finally, different voluntary and mandatory methods to increase the take-up of retrofit ADAS are examined, before a cost-benefit assessment for the different systems and measures concludes the report.

Major technical issues regarding technical feasibility include limitations on access to vehicle resources. Due to liability and data security reasons, vehicle manufacturers are often unwilling to provide access to vehicle actuators. Hence, only ADAS which warn the drivers, are included in the study, excluding ADAS, which intervene through the vehicle actuators. Vehicle manufacturers are also reluctant to provide access to in-vehicle data. Standard in-vehicle interfaces provide information to a limited set of data, but not to all data required by retrofit ADAS, such as turn indicator signal. Retrofit ADAS manufacturers have found solutions to overcome this issue by identifying the data on the in-vehicle network and listening to the traffic on the in-vehicle network. Regarding the in-vehicle display, there are several technologies available which connect retrofit systems to the in-vehicle display. However, these remain unused by current retrofit ADAS.

The following retrofit ADAS are studied in this report:

- FCW Forward collision warning, both VEH (vehicles) and PCD (pedestrians and cyclists)
- LDW Lane departure warning
- SLI Speed limit information
- DDR-ADR Advanced driver distraction warning
- REV Reversing detection
- TPM Tyre pressure monitoring system
- VIS-DET Detection and warning of pedestrians and cyclists nearby the front or side of the vehicle
- 112 eCall

The functions FCW (VEH + PCD), LDW and SLI are often found in a single device, and hence they are included as a bundle in this report.

The technical performance of retrofit ADAS is the same as factory fit ADAS using the same technology, assuming the devices are installed according to appropriate guidelines. Therefore professional installation is recommended.
Starting from estimates from the development of the vehicle fleet and estimates regarding the penetration rates of factory-fitted systems, estimates are made for the deployment of retrofit ADAS systems. Due to the adoption of Regulation (EU) 2019/2144, the number of vehicles with ADAS systems will increase in the coming years. Without any voluntary or mandatory measures, the number of vehicles with retrofit ADAS is however expected to remain small.

Voluntary measures applied in EU to promote the uptake of retrofit ADAS include awareness raising measures, subsidies and other financial incentives (e.g. tax advantages, insurance discounts) and public procurement requirements. In addition, there is a limited number examples where Urban vehicle access regulations or other traffic regulations are used at a local level to regulate access of N2, N3, M2 and/or M3 vehicles with and without VIS-DET.

For the Cost-Benefit Assessment, two different sets of policy measures are assessed. Policy option 1 (PO1) includes both a financial incentive and an awareness campaign. The effectiveness of voluntary measures is based on literature study. The awareness campaign is expected to increase the penetration rate of retrofit ADAS to grow with 3 percentage points. The effectiveness of a financial instrument is estimated at 3.7 percentage points per year. Policy option 2 (PO2) assumes a mandatory deployment of retrofit ADAS for all vehicles during a period of 2 years (2026–2027).

Based on a literature study, the safety effects of the systems on the number of fatalities and injury accidents are estimated. The direct and indirect safety effects of ADAS were identified based on the ADAS descriptions defined in the early stages of this project and based on findings from earlier studies. The safety effects were quantified based on the estimates of the safety effects from earlier studies. Based on this analysis, the highest safety benefits could be expected for LDW, SLI, 112 eCall and DDR. The bundle (FCW, SLI and LDW) was estimated to reduce road fatalities by 12.9–27.2% and injury accidents by 8.4–23.4% at 100% penetration, against the baseline in which 0% of vehicles are fitted with ADAS (neither factory-fitted nor retrofitted). For the different policy options, this results in a reduction of fatalities of 1.2–2.6% for the voluntary measures (PO1) and of 2.4–5.2% for the mandatory measures (PO2).

The CBA is performed for the evaluation period 2026-2041. Estimates for the costs on purchase, maintenance, inspection, repair and campaign costs, are based on literature study and expert assessment. The best result obtained is for VIS-DET, which offers a positive BCR for both policy options for M2&M3 vehicles: for voluntary measures the range is 1.5-5 and 2.2-7.1 for mandatory measures. The main reason for this is that the fleet is relatively small compared to the other vehicle classes (hence costs are rather low) and this vehicle category is involved in a relatively large number of collisions (hence the potential for a reduction in casualties is rather high). This implies that retrofitting VIS-DET in M2&M3 vehicles is considered to be cost-effective (e.g. the safety benefit exceeds the purchase, installation and policy-specific costs). Similarly the results for M2&M3 vehicles for SLI (0.3-2 for PO1 and 1-4.4 for PO2) are positive.

Different sensitivity analyses (changes in safety benefits; different monetisation of prevented casualties and discount rate; different costs assessment) were performed to verify the robustness of the CBA results.
1 INTRODUCTION AND BACKGROUND

1.1 Purpose of the document

This document is the final report of the project “Study on the feasibility, costs and benefits of retrofitting advanced driver assistance to improve road safety”, contracted by the European Commission, Directorate General for Mobility and Transport to the consortium formed by VTT and Ecorys.

1.2 Objectives of the study

The main objective of this study is to provide information on the feasibility, costs and benefits of retrofit Advanced Driver Assistance Systems (ADAS) for existing vehicles. This main objective is divided into three sub-objectives:

1. To prepare an inventory of ADAS available on the market which are retrofittable to existing vehicles.
2. To assess the feasibility and effectiveness of possible measures aiming to promote voluntary and mandatory ADAS retrofitting.
3. To perform an analysis of costs and benefits for various retrofit ADAS selected for more detailed assessment.

1.3 Background: ADAS in General Safety Regulation update

ADAS are vehicle-based intelligent safety systems, developed and deployed by vehicle manufacturers, which have the potential to improve road safety in the areas of crash avoidance, crash severity mitigation and protection, automatic post-crash communication of collisions or any integrated combination of the above (European Commission, 2016a). ADAS primarily seek to compensate for human error with intelligent technological solutions. ADAS therefore help to reduce the amount of fatalities and accidents in road traffic.

During the last several years in the EU, the accident reduction rate has been slower then needed to achieve the EU’s road safety targets of halving the number of road fatalities by 2020 (European Commission, 2018a). Through speeding up the penetration of ADAS in the vehicle fleet, the decrease of fatalities could also be speed up. The European Commission has already mandated several safety systems in recent years:

- Electronic Stability Control (ESC) on all new types of vehicles from 1.11.2011 and from 1.11.2014 for all new vehicles (Regulation (EC) No 661/2009);
- Advanced Emergency Braking with only vehicle detection capability (AEB-VEH) and Lane Departure Warning (LDW): both from 1.11.2013 for new types of Heavy Duty Vehicles and from 1.11.2015 for all new Heavy Duty Vehicles (Regulation (EC) No 661/2009);
- Tyre pressure monitoring systems (TPM) on passenger cars, for new types from 1.11.2012 and for all new vehicles from 1.11.2014 (Regulation (EC) 661/2009);
- 112 eCall on new types of passenger cars and vans from 31.3.2018 onwards (Regulation (EU) 2015/758).

Unfortunately, during the last several years in the EU, the accident reduction rate has been slower then needed to achieve the EU’s road safety targets of halving the number of road fatalities by 2020 (European Commission, 2018a). Through speeding up the penetration of ADAS in the vehicle fleet, the decrease of fatalities could also be speed up. The European Commission has proposed legally mandating new vehicle safety measures (including ADAS technologies) to be deployed on all new vehicles (European Commission, 2018b), through updating Regulation (EC) No 661/2009, also known as
the General Safety Regulation (GSR). In the framework of the proposal an extensive impact assessment of ADAS has been performed (European Commission, 2018c), which was based on a supporting study from Seidl et al. (2017). According to the impact assessment, applying a combination of ADAS to new vehicles is considered to not only be technologically feasible, but also cost-beneficial. The mandated systems are expected to prevent 24,794 fatalities and 140,740 serious injuries over the period 2021-2037 (European Commission, 2018c).

Regulation (EU) 2019/2144 was adopted by the European Parliament and the Council of the EU in November 2019. The new rules take effect from June 2022 for new types of vehicles and from June 2024 for existing types.

- All new vehicles will have to include:
  - Intelligent speed assistance to make a driver aware when exceeding the speed limit
  - Driver drowsiness and attention warning
  - Advanced driver distraction warning to help keep driver’s attention focused on the traffic situation (for new types from June 2024, for existing types from June 2026).
  - Emergency stop signal in the form of a light, signalling road users behind the vehicle that the driver is braking suddenly
  - Reversing detection system to avoid collisions with people and objects behind the vehicle, with the help of a camera or a monitor
  - Tyre pressure monitoring system warning the driver when a loss of tyre pressure occurs.
  - Alcohol interlock installation facilitation allowing fitting of aftermarket alcohol interlock devices
  - Event data recorder to register relevant data shortly before, during, and immediately after a road accident (for trucks and buses new types from November 2025 and for existing types from November 2028).

- Passenger cars (class M1) and light commercial vehicles (class N1) have to include:
  - Advanced emergency-braking system. Detection of obstacles and moving vehicles only in the first phase, detection of pedestrians and cyclists as well in the second phase (June 2024 for new types and June 2026 for existing types).
  - Emergency lane-keeping system

- Trucks (classes N2,N3) and buses (classes M2,M3) have to include:
  - Detection and warning of pedestrians and cyclists nearby the front or side of the vehicle
  - Direct vision features, involving new cab design. Enhancing the direct visibility of pedestrians, cyclists and other vulnerable road users from the driver’s position by reducing blind spots in front and to the side of the driver as much as possible. Direct vision technology should be applied to new types as from December 2025 and for existing types from December 2028.
2 METHODOLOGY

2.1 Technical feasibility

The technical feasibility assessment of retrofit ADAS started with a literature review of the retrofit ADAS products. The safety measures (including ADAS), which are becoming mandatory in new vehicles in the update of the GSR, were the starting point and the scope of the study. The literature review focused on identifying the list of potential retrofit ADAS, the types of retrofit ADAS products on the market today and technologies available expected performance and safety benefits, the need for standardisation or certification procedures as well as various other topics. In addition, the need for maintenance and calibration of the systems during or after their initial installation was studied.

An inventory of retrofit ADAS available on the market which can be installed in existing vehicles was prepared. For each system, the inventory included information on its performance, limitations and installation requirements. In addition, an assessment of the current market penetration of the systems was done together with information regarding the cost of the system, including installation and maintenance costs (if appropriate). The inventory information was collected not only from the provider (manufacturer) of the systems, but also from other sources independent from the providers such as internet search engines and online stores. The stakeholder consultation was performed through a number of targeted interviews of vehicle technology importers, retrofit ADAS manufacturers, Tier1 suppliers and OEMs in order to complement the inventory of retrofit ADAS systems. The selection of retrofit ADAS for the study and finally the technical and retrofit ADAS performance assessment was carried out as an expert estimation supported by feedback from stakeholders.

2.2 Assessment of benefits

The estimation of the selected retrofit ADAS’ safety potential was conducted by assessing the proportion of accidents considered preventable with the use of the retrofitted systems and assessing the effectiveness of the different retrofitted systems for achieving these safety benefits.

The safety impact assessment was based on the descriptions of ADAS and their functionalities. Based on these, the share and type of vehicles where the ADAS can be retrofitted were identified (i.e. excluding the share of vehicles where ADAS is already built-in or retrofit is not possible).

The safety impact assessment of the selected retrofit ADAS followed the method proposed by Kulmala (2010) where applicable. Safety impacts were identified based on existing literature and expert assessments, since no field studies were conducted as part of this study. The assessment process started with a careful review of findings of the safety effects of ADAS from earlier studies, e.g. Cuerden 2018, SWD/2018/190 (European Commission, 2018c), and relevant EU-projects such as eIMPACT (Wilmink et al., 2008) and VRUITS (Bax at el., 2016).

The safety impact assessment followed the generally accepted theoretical background according to which the traffic safety consists of three dimensions, which are (1) exposure, (2) risk of an accident to take place during a trip and (3) consequences (= risk of an accident to result in injuries or death) (Nilsson 2004). In order to identify all possible impacts of investigated ADAS (both positive and negative impacts on road safety; direct, indirect and unintended effects of systems), the analysis utilised a set of nine mechanisms via which Intelligent Transport Systems (ITS) can affect road user behaviour and thereby road safety:
Study on the feasibility, costs and benefits of retrofitting ADAS to improve road safety

- Mechanism 1: Direct modification of the task of road users
- Mechanism 2: Direct influence by roadside systems
- Mechanism 3: Indirect modification of user behaviour in many, largely unknown ways
- Mechanism 4: Indirect modification of non-user behaviour
- Mechanism 5: Modification of interaction between users and nonusers
- Mechanism 6: Modification of road user
- Mechanism 7: Modification of modal choice
- Mechanism 8: Modification of route choice
- Mechanism 9: Modification of accident consequences

These direct and indirect safety effects of ADAS were identified and documented based on the findings from earlier studies. The indirect effects refer to, for example, behavioural adaptation, changes in exposure of road users and/or changes in the behaviour of non-users (as mentioned in the nine mechanisms above).

Finally, the safety effects were calculated based on the estimates of the safety effects from earlier studies (typically including a range from low to high). The first estimates of safety effects considered 100% penetration rate and 100% usage of ADAS. In the CBA calculations for this study, different penetration rates were used, but a 100% usage rate was used throughout.

The estimates of safety effects were applied to the EU-28 road accident data to determine the overall effect in terms of number of fatalities and number of injury accidents saved, compared to a baseline. In order to establish this baseline, the casualty baseline used in SWD/2018/190 (European Commission, 2018c) to assess the expected effect of the proposed measures on the number of casualties was updated as part of this study. The results of this exercise are presented in Annex D.

The assessment of safety effects was first conducted for the individual retrofit ADAS. Following this, the safety effects of a bundle of retrofit ADAS were estimated based on the results of the safety effects of individual retrofit ADAS.

The CARE database was used for the analysis, since it covers accidents on a pan-European level. The total number of fatalities and injury accidents in EU-28 in 2016 were taken from the statistical pocketbook (European Commission, 2018d). The first year of an estimated accident reduction due to retrofitting ADAS was set at 2020.

The total number of fatalities and injury accidents in the EU-28 used in the calculation are presented in Table 1. The figures for future years (2030 and 2041) are estimated based on SWD/2018/190.

<table>
<thead>
<tr>
<th></th>
<th>2016</th>
<th>2030</th>
<th>2041</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatalities</td>
<td>25,651</td>
<td>21,453</td>
<td>18,624</td>
</tr>
<tr>
<td>Injury accidents</td>
<td>1,099,075</td>
<td>1,310,522</td>
<td>1,218,570</td>
</tr>
</tbody>
</table>

Table 1. Total number of fatalities and injury accidents in the EU-28 used to calculate the baseline scenario, i.e. after GSR update coming into force (European Commission, 2018d; European Commission, 2018c).

In Chapter 6, a thorough overview of the methodology for these policy specific cost components is offered.

2.3 **Assessment of costs**

The different policy options are described in Chapter 5. The main cost factor in the analysis are the purchasing costs of aftermarket ADAS systems. In the CBA, the costs
described by SWD/2018/190 are used. These costs are further augmented by also determining the installation costs of aftermarket devices, which differ from installation costs (if any) of factory-fitment of ADAS.

Next to purchase and installation costs, costs that are specific for different policy options are considered. These costs relate to the measures taken. In Chapter 6, a thorough overview of the methodology for these policy specific cost components is presented.

2.4 Cost-benefit analysis

Apart from the qualitative assessment of advantages and disadvantages of each policy option, their socio-economic costs and benefits were assessed in quantitative terms using the cost-benefit technique (CBA). The effects of the options for individual stakeholders and society are quantified in different policy options. In this CBA, three policy options are considered.

The first policy option (PO0) forms the ‘baseline’ development of quantifiable indicators. The baseline scenario describes the ‘do-nothing’ policy options, and therefore quantifies the development of indicators in case no (additional) policy measures are taken. Even if no additional policy measures are adopted, existing policy measures might also have an impact on costs and benefits that originate in coming years. If these impacts are not corrected for, the CBA performed in this study might over- or underestimate effects as the impacts might incorrectly be attributed to the retrofitting of ADAS.

The second policy option (PO1) assesses the (quantified) costs and benefits of measures that voluntary stimulate vehicle owners to retrofit their vehicle with aftermarket ADAS products. A detailed description of this policy option is provided in Section 5.1.

The third policy option (PO2) assesses the (quantified) costs and benefits of mandatory measures, in which vehicle owners are mandated to retrofit their vehicle with aftermarket ADAS products from a given year. A detailed description of this policy option is provided in Section 5.2.

The costs and benefits of PO1 and PO2 are compared to the costs and benefits in PO0. This is common practice in a CBA and ensures that only costs and benefits directly resulting from policy measures concerned in this study enter the analysis.

Only those effects, which have an impact on the welfare of the citizens of the European Union, have been considered in our CBA. This means that a reduction in the use of labour or materials was regarded as a benefit to society, even though it may involve less turnover/work for some sectors. According to normal practice in cost-benefit analyses, it was assumed that those resources can be spent on alternative uses, like producing other products or services.

Costs and benefits were quantified as much as possible, using information from public sources like Eurostat (2018). In various cases, estimates were made on basis of partial information or expert judgement. Costs and benefits were expressed as closely as possible to the price level in 2019. The time horizon used in the analysis was set at 15 years, which is the same horizon as in SWD/2018/190. The results of the CBA are presented in Chapter 6.

2.5 Stakeholder consultation

During the study, stakeholders were consulted during several phases. In the first phase, stakeholders (OEMs, device manufacturers and importers) were interviewed via phone or physically on the technical feasibility, costs and benefits of retrofitting ADAS. At a workshop held on 11.6.2019, feedback was collected from stakeholder representatives regarding the technical feasibility, safety impact and cost-benefit assessment.
methodology, cost estimates and safety benefits. The feedback of the participants is listed in Annex G, and is also integrated in this study. Table 2 lists the organisations who provided feedback.

**Table 2. Organisations that provided feedback to this study.**

<table>
<thead>
<tr>
<th>Stakeholder Group</th>
<th>Subgroup</th>
<th>Organisation</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle manufacturers &amp; subscribers</td>
<td>Automotive OEM manufacturers Tier 1 supplier</td>
<td>Volvo Cars</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>European level organisation</td>
<td>Continental</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ZF Friedrichshafen</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>European Association of Automotive Suppliers (CLEPA)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ertico</td>
<td>X</td>
</tr>
<tr>
<td>Device manufacturers</td>
<td>Automotive device manufacturers</td>
<td>Mobileye</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Importers</td>
<td>Piirla</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OnePro</td>
<td></td>
</tr>
<tr>
<td>Vehicle service</td>
<td>Maintenance</td>
<td>European Garage Equipment Association (EGEA)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Vehicle inspection</td>
<td>Opus Group</td>
<td>X</td>
</tr>
<tr>
<td>Road users</td>
<td>Driver associations</td>
<td>International Automobile Federation (FIA)</td>
<td>X*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>International Road Union (IRU)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Driver training</td>
<td>TTS</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ProDrive</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Vulnerable road users</td>
<td>International Federation of Pedestrians (IFP)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>European Cyclists’ Federation (ECF)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Federation of European Motorcyclists Associations (FEMA)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Road safety experts</td>
<td>European Transport Safety Council (ETSC)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Insurance companies</td>
<td>AllSecur (Allianz Direct)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AON</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Public authorities</td>
<td>Traficom (Finland)</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Veilig Verkeer Nederland (NL)</td>
<td>X</td>
</tr>
</tbody>
</table>

* Besides an interview, a presentation was given on a FIA workshop in Brussels on 19 September 2019
3 TECHNICAL FEASIBILITY OF RETROFITTING ADAS

3.1 Interests in retrofitting

The increasing uptake of ADAS and the growing number of ADAS requirements for new vehicles has generated interest in retrofitting older vehicles with such systems. Systems which do not interfere with vehicle control, i.e. take over the driver’s task, are easier to retrofit (Alkim, 2011). For example, lane departure warning systems, which only produce a warning if the vehicle crosses lane markings, can generally be retrofitted, as only a camera is essentially needed to detect lane markings and a speaker or screen to produce the warning (Alkim, 2011). However, systems like retrofit lane departure warning require some vehicle data (e.g. turning indicator signal) to work properly. On the other hand, an automatic lane-keeping system, which would require the ADAS to take over the steering of the vehicle if it crosses lane markings, may require factory fitting and thus involve a relatively more complex procedure (Alkim, 2011). The Specialty Equipment Market Association has identified integrating ADAS with original vehicle control systems as a key challenge for retrofitting aftermarket systems (Imlay, 2017).

3.2 Main technical issue with ADAS retrofitting: access to in-vehicle resources

The possibility to retrofit ADAS is mainly restricted by access to in-vehicle data (and actuators). This issue was elaborated in the study of McCarthy (2017) for the European Commission, on Access to In-vehicle Data and Resources.

Some retrofit ADAS require real-time access to vehicle data (and actuators). However, this would only be possible with in-vehicle interface or on-board application platform options, presented by McCarthy (2017). There are safety and security issues related to these approaches and access is limited to non-safety critical data (McCarthy 2017, p. 89):

“Uncontrolled and unfiltered write access by third parties to the vehicle’s bus systems (including, for example, chassis CAN etc.) is considered unsafe by OEMs: Safety critical components, including such as the brakes and airbags, are controlled via signals on the bus system. If these were activated by a third party, this could indeed result in safety-relevant road incidents. Therefore, clearly safety critical functions, such as activating the brakes while driving, should be protected against access by third parties.”

“Limited write access could be granted to third parties to control selected actuators for non-safety critical events, such as unlocking the doors under certain preconditions.”

The position of OEMs in this matter is quite clear as stated in ACEA’s position paper (ACEA 2016):

“It is the vehicle manufacturer’s responsibility that the vehicle operates in a safe and secure manner. This is why any risk of attack on or access to the vehicle’s security electronics through external systems or software programmes that are not under the control of the vehicle manufacturer must be avoided. Even uncontrolled third-party access to vehicle functions or data that are not directly security-relevant could lead to risks through networking: enabling vehicle theft and remote door unlock, for example, as well as creating opportunities for fraud, such as mileage manipulation, improper creation and misuse of movement profiles or sale of personal data. Similarly, it must be avoided that critical safety functions such as braking would be affected negatively by the use of in-vehicle resources for third-party applications. To limit such risks, third parties shall not have direct in-vehicle access to data.”
3.2.1 Third-party access to in-vehicle data

Several retrofit ADAS need real-time in-vehicle data for optimal operation. This includes, among others, vehicle speed and turn indicator signal data. For passenger cars and vans, the only standardised access to real-time in-vehicle data is the OBD-II interface. McCarthy (2017) also states: “OBD-II allows access to a standardised set of data such as emissions, fault codes etc. Independent and authorised repairers and workshops use the current interface to query a fault code or DTC, flash or upgrade existing software in a dedicated ECU on the vehicle using an OBD connector. The OBD-II interface provides a method for easy access to in-vehicle data. The data observed is real time and of high quality. What the current OBD-II interfaces lack is sufficient protection/security measures to prevent any threats from the outside world to in-vehicle networks.”

Only a limited set of data is standardised, and this set does not include all data which is needed for optimal ADAS operation such as turn indicator data. The in-vehicle data on the CAN bus varies across different vehicle set-ups and models, even if produced by the same vehicle manufacturer. The CAN bus specifications are kept confidential by the OEMs.

Some manufacturers of retrofit ADAS products have found access to a limited set of in-vehicle (CAN bus) data. Some third-party developers have utilised CAN bus “sniffers” to read in-vehicle data and have collected databases of various CAN bus data for different vehicles. These databases can be used to decode a limited set of real-time CAN bus data and used for retrofit in-vehicle systems. By only reading (not writing) CAN bus data, third-party developers try to avoid any potential liability, safety or regulatory issues. The installation of these retrofit systems is also brand and model specific.

In-vehicle data access for heavy duty vehicles is available via the open FMS (Fleet Management Systems) standard\(^2\), which has been introduced by major truck manufacturers in 2002 and by major bus and coach manufacturers in 2004. The in-vehicle FMS interface provides in-vehicle data to third-party systems related to fleet management applications. The amount of data provided on the interface of each vehicle manufacturer depends on manufacturer, model, production year, and installed ECUs. Some real-time FMS-data may be useful for listed retrofit ADAS.

3.2.2 Third-party access to in-vehicle display

Standardised access to the in-vehicle display for infotainment has become available during the past years for smartphone-car connectivity. This enables smartphone apps, such as navigation, music and other certified phone apps, to run on the smartphone and to use them via the dashboard display and the car’s speakers. Both the car and smartphone must support the connectivity. There are several de facto standards for such connectivity, including Android Auto\(^3\) and Apple CarPlay\(^4\). In addition, MirrorLink is an open (ETSI TS 103 544 series) standard for smartphone-car connectivity that allows smartphone apps to be projected on car In-Vehicle Infotainment (IVI) systems. Car manufacturers may support one or two of these connectivity methods, but this varies a lot between different vehicle brands and models.

In principle, this kind of car connectivity could also be utilised for retrofit ADAS systems in order to utilise the vehicle display as a resource. However, the interfaces have been designed for smartphone connectivity and there are no other retrofit devices on the market, which would utilise these methods. In addition, the infotainment head unit may not always be suitable for showing any ADAS information or alerts, as it is used to control various in-vehicle systems such as climate control, radio, etc.

\(^3\) [https://www.android.com/auto/](https://www.android.com/auto/), Accessed 4.11.2019
3.2.3 Third-party access to in-vehicle actuators

Retrofit ADAS manufacturers may only read in-vehicle information, and do not have access to the in-vehicle actuators. The only exception is the speed limiter, which is widely used for heavy vehicles where speed limiters are mandatory, but is also available for other vehicle types. For the throttle control, speed limiter manufacturers use a bypass to limit the speed, either by applying feedback force directly on the throttle pedal or by inserting a device between the Electronic Accelerator Pedal and the connection to the engine control.

**Retrofit self-driving kits**

Today, there are several retrofit self-driving kits and prototypes available from start-ups, such as Comma.ai, Kopernikus Automotive, Polysync.io, AutonomousStuff, etc. These start-ups have found an access to in-vehicle systems of a limited number of passenger cars in order to control the steering, brake and throttle with software. These vehicles are usually quite new, and equipped with factory fitted Adaptive Cruise Control and Lane Keep Assist functionalities, which are utilised to control the vehicle. However, for example Comma.ai sells only hardware but not any software to control the vehicle, which it offers as free open source software for research purposes only (Comma.ai, n.d.). Therefore, Comma.ai avoids any potential liability, safety or regulatory issues.

There are also some retrofit systems, which have setup mechanical actuators to control the steering wheel and the pedals of a car, such as X-matik. These mechanical retrofits can work with any car, but cannot be an easily scalable solution as each vehicle has different constructions for controls. In general, none of these retrofit solutions to access in-vehicle actuators can be considered as a scalable product or potential solution due to liability reasons.

3.2.4 Conclusion

In conclusion, retrofit ADAS may currently have limited real-time access to in-vehicle data, but cannot get access to actuators such as brakes, which are needed for certain listed ADAS. This issue is unlikely to change in the near future. The study of McCarthy (2017) does not suggest that this kind of access to in-vehicle systems would become available in any of the proposed technical solutions. Therefore, this makes intervening ADAS impossible for retrofitting and are thus out of scope for this study.

3.3 Selection of ADAS to the retrofit study

The starting points for this study are the ADAS (and their respective vehicle categories) included in proposal for the GSR (European Commission, 2018b). The acronyms used in the report are the acronyms used in the SWD/2018/190 (European Commission, 2018c). The function descriptions are based on the updated GSR, Regulation (EU) 2019/2144.

Additionally, 112 eCall has been included to the study at the request of the European Commission. The potential for retrofitting these ADAS has been assessed by the technical ADAS experts in the project team. In addition, each ADAS has been assessed to be included in the study either as is, as a version downgraded to only provide a warning, or considered out-of-scope for this study. The selection of retrofit ADAS to the study has been discussed together with the stakeholders in the retrofit ADAS workshop and in separate interviews.

---

5 [https://comma.ai/](https://comma.ai/), Accessed 4.11.2019
7 [https://polysync.io/](https://polysync.io/), Accessed 4.11.2019
3.3.1 Retrofit ADAS, which are included in this study

**Advanced emergency braking for obstacles and moving vehicles ahead (AEB-VEH)**

AEB systems can automatically detect a potential collision and activate the vehicle braking system to decelerate the vehicle with the purpose of avoiding or mitigating a collision (Regulation (EU) 2019/2144). AEB-VEH systems can detect obstacles and moving vehicles.

⇒ OEMs will not grant access in the vehicle bus for retrofit systems; hence, retrofit systems cannot control the vehicle actuators such as brakes. Therefore, only warnings for the driver are possible with retrofit ADAS. The downgraded function of AEB-VEH is Forward Collision Warning (FCW-VEH), which provides audio-visual warnings to the driver when it detects a potential collision with other vehicles.

⇒ Advanced emergency braking is already mandatory for new buses (M2, M3) and trucks (N2, N3) from 2015. The estimated penetration of AEB for Heavy Duty Vehicles is about 34% and in 2025, when the potential measures start having an effect, 68% (Table 10), so the potential market during the evaluation period is not high.

⇒ Retrofitting FCW-VEH is included in this study for M1 and N1 vehicles.

**Advanced emergency braking for pedestrians and cyclists (AEB-PCD)**

AEB-PCD systems also can detect potential collisions with pedestrians and cyclists. OEMs will not grant access in the vehicle bus for retrofit systems; hence retrofit systems cannot control the vehicle actuators such as brakes. Therefore, only warnings for the driver are possible with retrofit ADAS. The downgraded warning-only function of AEB-PCD is FCW-PCD (Forward Collision Warning for pedestrians and cyclists).

⇒ Retrofitting FCW-PCD is included in this study for M1 and N1 vehicles.

**Advanced Driver Distraction warning (DDR-ADR)**

Advanced driver distraction recognition warning is a system that helps the driver to continue to pay attention to the traffic situation and that warns the driver when he or she is distracted (Regulation (EU) 2019/2144).

Driver distraction can be detected through cameras.

⇒ Retrofitting DDR-ADR is included in this study.

**Intelligent speed assistance (ISA-VOL)**

'Intelligent speed assistance' is a system aiding the driver in maintaining the appropriate speed for the road environment by providing dedicated and appropriate feedback (Regulation (EU) 2019/2144).

Intelligent speed assistance systems shall have the following minimum specifications (Regulation (EU) 2019/2144):

(a) it shall be possible for the driver to be made aware through the accelerator control, or dedicated, appropriate and effective feedback, that the applicable speed limit is exceeded;
(b) it shall be possible to switch off the system. Information about the speed limit may still be provided, and the intelligent speed assistance system shall be in normal operation mode upon each activation of the vehicle master control switch;
(c) the dedicated and appropriate feedback shall be based on speed limit information obtained through observation of road signs and signals, based on infrastructure signals or electronic map data, or both, made available in-vehicle;
(d) it shall not affect the drivers’ possibility to exceed the system’s prompted vehicle speed;
(e) its performance targets shall be set in order to avoid or minimise the error rate in real driving conditions.
⇒ Haptic feedback to the accelerator pedal may be difficult to implement as a retrofit. Speed Limit Information (SLI) is the downgraded ADAS function, which knows and communicates the speed limit to the driver (Euro NCAP, 2018b).
⇒ Retrofitting SLI is included in this study.

Emergency Lane-keeping (LKA-ELK)

An Emergence Lane-keeping system assists the driver in keeping a safe position of the vehicle with respect to the lane or road boundary, at least when a lane departure occurs or is about to occur and a collision might be imminent (Regulation (EU) 2019/2144).

⇒ OEMs will not grant access to the vehicle bus for retrofit systems; thus, they cannot control the vehicle actuators such as steering. Therefore, only warnings for the driver are possible with retrofit ADAS. The downgraded warning-only function of LKA-ELK is lane departure warning (LDW).
⇒ LDW, which warns the driver that the vehicle is drifting out of its travel lane (Regulation (EU) 2019/2144), is already mandatory since 2015 on new Heavy Duty Vehicles. The estimated penetration of LDW is about 38% and in 2025, when the potential measures start having an effect 71% (Table 10), so the potential market is not high.
⇒ Retrofitting LDW is included in this study for M1 and N1 vehicles.

Reversing detection system (REV)

A reversing detection system means a system to make the driver aware of people and objects at the rear of the vehicle with the primary aim of avoiding collisions when reversing (Regulation (EU) 2019/2144). The system should indicate of the presence of a vulnerable road user, either (indirectly) visible or invisible to the driver when reversing, but without active intervention by the system itself. (European Commission, 2018c).

⇒ Retrofitting REV is included in this study.

Tyre pressure monitoring system (TPM)

A tyre pressure monitoring system (TPM) is a system fitted on a vehicle which can evaluate the pressure of the tyres or the variation of pressure over time and transmit corresponding information to the user while the vehicle is running (Regulation (EU) 2019/2144). TPM is already been mandatory for new passenger cars from 2014.

Tyre pressure is measured either directly, through sensors integrated in e.g. the tyre valve, or indirectly, e.g. through monitoring individual wheel speeds. Direct tyre
pressure monitoring systems, based on sensors integrated inside the tyre or in the tyre valve, are suitable for retrofitting.

- **Retrofitting TPM is included in this study.**

**Vulnerable road user detection and warning on front and side of vehicle (VIS-DET)**

Vulnerable road user detection and warning on front and side of vehicle uses environmental sensing or camera monitoring solutions to draw the attention of the driver to nearby vulnerable road users. The system clearly indicates the presence and the location of a vulnerable road user in or close to the vehicle’s path, if a collision is likely to occur and the driver has not taken any countermeasures. The system should especially indicate the presence of pedestrians and cyclists, either visible or invisible to the driver, when they are close to the vehicle’s front edge and the vehicle is about to begin accelerating from a stop (for instance for a truck stopped at a zebra crossing). This measure’s purpose is to avoid collisions with persons, but without active intervention by the system itself. (European Commission, 2018c).

- **Retrofitting VIS-DET is included in this study.**

**112 eCall**

112 eCall (already mandatory in new types of passenger cars and vans since 2018) is activated automatically as soon as in-vehicle sensors and/or processors (e.g. airbag) detect a serious crash. Once set off, the system dials the European emergency number (112), establishes a telephone link to the appropriate emergency call centre (Public Safety Answering Points – PSAPs) and sends details of the accident (Minimum Set of Data – MSD) to the rescue services, including the time of incident, the accurate position of the crashed vehicle and the direction of travel. eCall can also be triggered manually by pushing a button in the car, for example by a witness to a serious accident. (European Commission, 2019).

- The eCall standards are ready only for M1 and N1 vehicles. The eCall standards for heavy vehicles (M2, M3, N2 and N3) are not fully established. Furthermore, there are some critical open issues such as the automatic triggering mechanism and sources of additional data (including cargo information for trucks and number of passengers for buses). In addition, there are no retrofit eCall devices available on the market for heavy vehicles. Therefore, retrofit eCall for heavy vehicles is currently not technically feasible and is not included in the scope of this study.

- Typically, retrofit eCall devices are standalone equipment, and have dedicated hardware for communication functions, determining vehicle location as well as sensing an accident and triggering eCall. It has been stated by Bojkov et al., (2016), that without minimum requirements, the rollout of retrofit eCall devices may involve some major risks including PSAP overloading with false direct 112 eCalls and PSAP denial of service to other road users. The CEF funded project sSAFE (Aftermarket eCall for Europe) (sSAFE, 2019), focuses on definition of these physical and operating requirements for aftermarket 112 eCall in-vehicle devices. The technical feasibility and cost assessment of retrofit 112 eCall will be performed with currently available information. The assessment may change when the results of the sSAFE project are available.

- **Retrofitting 112 eCall is included in this study** for passenger cars and vans.
3.3.2 Retrofit ADAS, which are not included in this study

As described above, currently, retrofit ADAS can get limited real-time access to in-vehicle data but cannot get access to actuators, such as brakes, which is needed for certain listed ADAS. Therefore, this makes intervening ADAS impossible for retrofitting and therefore they are not technically feasible as retrofit ADAS.

**Driver drowsiness and attention warning (DDR-DAD)**

Drowsiness and attention detection is a system that assesses the driver’s alertness through vehicle systems analysis and warns the driver if needed detects driver inattention (Regulation (EU) 2019/2144).

⇒ OEMs will not grant access in the vehicle bus for retrofit systems; thus, they cannot acquire necessary vehicle information such as steering data. Although the steering data is obtainable from some heavy vehicles (at least buses) via FMS, this data is not easily available in passenger cars and vans. Therefore, only camera-based drowsiness and attention detection will be included in this study, as there are already retrofit devices on the market that include both DDR-DAD and DDR-ADR functionality in the same device.

⇒ **Retrofitting DDR-DAD is not included in this study, but a combination of DDR DAD + ADR is included.**

**Event (accident) data recorder (EDR)**

⇒ An Event (accident) data recorder is a system with the only purpose of recording and storing critical crash-related parameters and information shortly before, during and immediately after a collision (Regulation (EU) 2019/2144). The EDR stores a range of crucial anonymised vehicle data over a specific timeframe before, during and immediately after a crash, usually triggered by airbag deployment Regulation (EU) 2019/2144). Data includes the vehicle’s speed, braking, position and tilt of the vehicle on the road, the state and rate of activation of all its safety systems, 112-based eCall in-vehicle system, brake activation and relevant input parameters of the on-board active safety and accident avoidance systems (Regulation (EU) 2019/2144).

Recorders should be capable of recording and storing data in such a way that the data can only be used by Member States to conduct road safety analysis and assess the effectiveness of specific measures taken without the possibility of identifying the owner or the holder of a particular vehicle on the basis of the stored data.” (Regulation (EU) 2019/2144). According to the study from Hynd & McCarthy (2014) almost all new vehicles in 2014 have been fitted with an EDR. The study states: “There may also be considerable legal complications related to mandatory fitment of continuous journey monitoring equipment. It is therefore recommended that these systems are seen as complimentary to EDR, rather than an alternative technical solution.” (Hynd & McCarthy, 2014, pp. 42–43).

⇒ The EDR requires much information from the in-vehicle data bus (including data from activation of safety systems, etc.), and OEMs will not grant access to this data for retrofit systems. Additionally, reverse engineering this data from various vehicle systems would most likely require unreasonable effort in light of its market potential. The requirements set in Regulation (EU) 2019/2144) exclude the retrofit black boxes and other similar pay-as-you-drive insurance devices, which are available on the market today.

⇒ **Therefore, retrofitting EDR (event data recorder) is not feasible and not included in this study.**
Emergency stop signal (ESS)

Emergency stop signal is a light-signalling function to indicate to other road users to the rear of the vehicle that a high retardation force is being applied to the vehicle relative to the prevailing road conditions (Regulation (EU) 2019/2144).

⇒ OEMs will not grant access to the in-vehicle CAN bus for retrofit systems; thus, they cannot control the brake lights. Therefore, retrofitting emergency stop signal is not feasible and not included in this study.

3.3.3 Safety measures which are out-of-scope

The following systems listed in the Regulation (EU) 2019/2144, which are passive safety systems or related to vehicle re-design or equipment installation facilitation, are out-of-scope for this retrofit ADAS study:

- Alcohol interlock installation facilitation
- Full-width frontal occupant protection crash test
- Head impact zone enlargement
- Pole side impact occupant protection
- Vulnerable road user improved direct vision from driver’s position

3.3.4 Overview

Table 3 gives an overview of the ADAS systems included in Regulation (EU) 2019/2144, the relevant vehicle types, the implementation dates, as well as the respective retrofit ADAS, which are addressed in this study.
Table 3. ADAS included in this study and applicable vehicle types.

<table>
<thead>
<tr>
<th>ADAS in Regulation (EU) 2019/2144</th>
<th>Vehicle type and implementation date*</th>
<th>Retrofit system addressed in the study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acronym</td>
<td>Description</td>
<td>M1, N1</td>
</tr>
<tr>
<td>AEB-VEH</td>
<td>Advanced emergency braking for obstacles and moving vehicles</td>
<td>B</td>
</tr>
<tr>
<td>AEB-PCD</td>
<td>Advanced emergency braking for pedestrians and cyclists</td>
<td>C</td>
</tr>
<tr>
<td>ALC</td>
<td>Alcohol interlock facilitation</td>
<td>B</td>
</tr>
<tr>
<td>DDR-DAD</td>
<td>Driver drowsiness and attention warning</td>
<td>B</td>
</tr>
<tr>
<td>DDR-ADR</td>
<td>Advanced driver distraction warning</td>
<td>C</td>
</tr>
<tr>
<td>EDR</td>
<td>Event data recorder</td>
<td>B</td>
</tr>
<tr>
<td>ESS</td>
<td>Emergency stop signal</td>
<td>B</td>
</tr>
<tr>
<td>ISA</td>
<td>Intelligent speed adaptation</td>
<td>B</td>
</tr>
<tr>
<td>LKA</td>
<td>Emergency lane-keeping system</td>
<td>B</td>
</tr>
<tr>
<td>REV</td>
<td>Reversing detection</td>
<td>B</td>
</tr>
<tr>
<td>TPM</td>
<td>Tyre pressure monitoring system</td>
<td>B</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>Detection and warning of pedestrians and cyclists nearby the front or side of the vehicle</td>
<td>-</td>
</tr>
<tr>
<td>112 eCall</td>
<td>112 eCall**</td>
<td>2018</td>
</tr>
</tbody>
</table>

* Implementation dates:
  B: 6/2022 new types, 6/2024 new vehicles;
  C: 6/2024 new types, 6/2026 new vehicles;
  D: 12/2025 new types, 12/2028 new vehicles

** Not included in Regulation (EU) 2019/2144.

*** Implementation date for new types

3.4 Retrofit ADAS Performance and Installation

3.4.1 Retrofit ADAS Performance

In general, retrofit ADAS can only provide warning assistance for the driver. The warning function is relatively simple to implement, as only a sensor (e.g. a camera), user interface and processing capacity are required. Installation is generally straightforward, since the retrofit ADAS are usually stand-alone devices including all required modules and functions. Retrofit ADAS will and can provide additional driver assistance through various warning strategies. When retrofit ADAS consist of sensors of sufficient quality, appropriate algorithms and intuitive user interfaces, they can add a welcome feeling of assistance through mere warnings, e.g. audible, visual or even tangible. Questions remain regarding sufficient sensor quality, capability of algorithms and user interface design. Another issue related to retrofit ADAS feasibility is the reliability and pricing of retrofit devices.

As an example, many retrofit ADAS devices on the market detect obstacles or lane markings using a camera, which may have limited functionality in adverse weather conditions such as fog or heavy rain. High-end factory-fit systems can better address...
adverse weather conditions since they can combine information from multiple sensors such as camera and radar sensors. For instance, Euro NCAP addresses low-light scenarios for AEB VRU (Euro NCAP, 2018a). In addition, detection devices in factory-fit systems are installed at optimized locations inside the vehicle, whereas the installation of retrofit systems can be restricted due to vehicle interior design and the requirement to avoid obstructions of the driver field of view. Therefore, retrofit ADAS may have reduced performance compared to a similar factory-fitted ADAS system, if installation of the system is not carried out properly.

The general view in the stakeholder consultation was that if the user may gain incentives or mandatory measures are in place, retrofit ADAS should be tested against e.g. UN/ECE or Euro NCAP requirements and tests. Standards and performance requirements for retrofit systems should not be less stringent than for factory-fitted systems. Additionally, only systems which truly provide safety benefits should be promoted, and retrofit ADAS (promoted or not) should not reduce traffic safety or consumers trust towards vehicle safety systems in general. Therefore, retrofit ADAS should be designed to maximize the effective warning rate while at the same time minimize the false warning rate. System responses to measures that might seem intrusive or annoying for the user can have undesirable safety outcomes wherein users disregard or disable the system (Braitman et al., 2010). Therefore, HMI design and human factors need to also be considered for retrofit ADAS. The quality of retrofit ADAS should be ensured, and driver acceptance of these systems must be gained in order to reach their potential safety benefits.

In general, the performance of the retrofit ADAS, selected to the study, can reach the same level as factory-fitted similar systems. Therefore, technical feasibility is estimated in this study only with the systems that can provide similar safety benefits as factory-fitted ones. Retrofit ADAS should also be installed to the vehicle in such a way that it will be always on when the ignition is turned on, as is required by UN/ECE regulations for factory-fitted systems. However, retrofit ADAS can be turned off or muted in a similar manner as factory-fitted ADAS, e.g. if it is distracting or annoying to the driver. Therefore, a professional garage or workshop should install retrofit systems, which may also ensure that the system is installed in the optimal position and receives calibration if needed. The garage or workshop can provide a certificate of the ADAS installation, e.g. if it is needed for any incentive.

This study focuses on standalone retrofit ADAS, including sensors, computing, Human-Machine-Interface (HMI), etc. Retrofit ADAS, which require e.g. a mobile phone of the driver for data communication, are excluded as reliability and availability of such systems may not at the same level. Some ADAS can be available as smartphone applications, but these usually assume that the mobile phone is self-installed to the windscreen by a consumer (e.g. camera-based application), which may lead to variable performance, and to obstruction of the view of the driver. Mobile phone based applications will not always be on or used. Moreover, when they are used, incoming unrelated messages and phone calls may distract the driver. Therefore, mobile phone based applications and systems may not provide the needed performance level and safety benefits and are therefore excluded from this study.

A combination of several retrofit ADAS with their own HMI (e.g. a display and different audio-visual warnings) on a vehicle may not be a viable solution or safe to use. Several warnings coming from multiple devices while driving is a safety risk. Especially in passenger cars, there is a limited space for additional displays and the field of view through the windscreen should not be limited. This notion also supports the benefits of professional retrofit ADAS installation. In addition, the bundling of several ADAS into a single product (with common HMI) can also reduce the need for additional retrofit HMIs in a vehicle.
3.4.2 Suitability of ADAS retrofitting for vehicle fleet

In general, retrofitting ADAS should be possible for all vehicles. However, for passenger vehicles and vans there may be some problems to access vehicle data from older vehicles, which do not have a CAN bus. However, the needed data can be usually read from other sources with higher installation costs.

Many vehicles on the road are relatively new (only a few years old) and have had some ADAS as factory optional equipment, but not purchased for the vehicle. According to the feedback from stakeholders, installation or reactivation of these ADAS afterwards is not technically and financially feasible. In many cases this would require additional hardware and software updates, which can be very expensive, and vehicle manufacturers do not have established support for this kind of activity.

3.5 Summary of retrofit ADAS technical feasibility

In this section, the following tables present a summary of the retrofit ADAS selected for this study, including their functionality, description, technical feasibility and performance assessment (Table 4 for all vehicles, Table 5 for passenger cars and light commercial vehicles and Table 6 for trucks and buses). The tables also include a short description of each ADAS availability as a retrofit product, installation requirements or recommendations as well as availability of test procedures, which could be used to validate their performance. The performance of each retrofit ADAS is compared to similar factory-fitted ADAS in vehicles today.

Table 4. Technical feasibility of retrofit ADAS for all vehicles.

<table>
<thead>
<tr>
<th>Retrofit ADAS</th>
<th>Technical feasibility and performance of retrofit ADAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLI</td>
<td>Retrofit SLI products on the market are camera based (combined with FCW and LDW) or map-based, integrated with e.g. navigators. Technical issues with SLI are similar as for factory-fitted ISA; e.g. up-to-date map data, conditional speed limits (e.g. speed limit dependent on rain). Professional installation and calibration required for camera-based SLI. Euro NCAP (2018b) test protocol (for speed assist systems) available, which can be used also for retrofit. UN/ECE test specifications are not yet available for factory-fitted ISA. No significant functional differences between factory-fitted and retrofit SLI solutions. SLI retrofitting is technically feasible</td>
</tr>
<tr>
<td>DDR -ADR</td>
<td>Retrofit DDR-ADR are usually based on cameras installed on the dashboard. Both factory-fit and retrofit DDR ADR are not yet mature enough. Introduction of retrofit DDR is assumed to be possible at the same time as factory fitted versions available and established Professional installation recommended. No test specifications yet available Performance of retrofit camera-based DDR expected to be similar to factory fitted DDR when technology matured. No significant functional differences between factory-fitted and retrofit solutions. DDR retrofitting is technically feasible</td>
</tr>
</tbody>
</table>
### Retrofit ADAS

<table>
<thead>
<tr>
<th>Retrofit ADAS</th>
<th>Technical feasibility and performance of retrofit ADAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>REV</td>
<td>Retrofit REV systems either consist of a camera, installed at the rear window and a display in the cockpit, or of parking sensors installed in the rear bumper and a warning device in the cockpit. Retrofit reverse cameras and parking sensors are widely available. Professional installation and calibration needed. UN/ECE proposal available (UN/ECE, 2019b). Test requirements for US light vehicles (FMVSS 111) available for camera-based systems. No significant functional differences between factory-fitted and retrofit solutions. <strong>REV retrofitting is technically feasible</strong></td>
</tr>
<tr>
<td>TPM</td>
<td>Retrofit tyre pressure monitoring systems are based on sensors integrated with the tyre, which communicate wirelessly with a display in the cockpit. For semi-trailers, which may be switched, establishing communication between the central unit in the tractor and the TPM sensors can be a problem, both for retrofit and factory-fitted systems. Professional installation recommended, but self-installation retrofit systems are also available. UN/ECE regulation 141 test procedures available (for M1 and N1 vehicles) and usable for retrofit systems. No significant functional differences between factory-fitted and retrofit solutions. <strong>TPM retrofitting is technically feasible</strong></td>
</tr>
</tbody>
</table>

### Table 5. Technical feasibility of retrofit ADAS for passenger cars and light commercial vehicles only.

<table>
<thead>
<tr>
<th>Retrofit ADAS</th>
<th>Technical feasibility and performance of retrofit ADAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCW (VEH &amp; PCD)</td>
<td>Several retrofit camera-based FCW products are available, offering both FCW-VEH and FCW-PCD (bundled with LDW). Radar based FCW is considered too expensive, especially for private vehicles. Professional installation and calibration needed. UN/ECE Regulation 131 for AEB-VEH for M2,N2,M3,N3 vehicles and draft UN/ECE Regulation 152 (UN/ECE, 2019a) for vehicle and pedestrian AEB for M1 and N1 vehicles. Euro NCAP &amp; NHTSA tests can be used also to retrofit FCW with minor modifications Retrofit camera-based FCW systems are developing fast and camera is the most cost-efficient technology available today. Performance of retrofit FCW-VEH and FCW-PCD is similar to factory-fitted FCW camera-based systems. No significant functional or performance differences between factory-fitted and retrofit solutions. <strong>FCW VEH &amp; PCD retrofitting is technically feasible</strong></td>
</tr>
</tbody>
</table>
Retrofit ADAS | Technical feasibility and performance of retrofit ADAS
--- | ---
LDW | Several retrofit camera-based LDW systems are available (bundled with FCW). Retrofit LDW requires access to a limited set of vehicle data, viz..the turn direction indicator. Without this data, LDW provides limited functionality.

Professional installation and calibration needed.

UN/ECE Regulation 130 for heavy vehicles & Euro NCAP tests for cars can be used also to retrofit LDW

No significant functional or performance differences between factory-fitted and retrofit solutions (if vehicle data used)

**LDW retrofitting is technically feasible**

112 eCall | All retrofit eCall devices on the market are TPS eCall devices, which call to a service operator instead of to the PSAP.

There are no minimum specifications or standards for aftermarket eCall products. Triggering of the eCall message is based on the sensors in the device. Retrofit eCall needs proper installation and advanced triggering method.

Professional installation recommended. It should be guaranteed that the retrofit eCall will work after car crash.

No test requirements or standards available for retrofit eCall products. The sSAFE (Aftermarket eCall For Europe) (sSAFE, 2019), started in 2019, aims to define the standards and specifications for aftermarket systems for eCall. It will also design a conformity scheme and conduct CBA for aftermarket eCall.

No significant functional differences between factory-fitted and retrofit solutions.

**eCall retrofitting is technically feasible (if upcoming minimum requirements applied)**

### Table 6. Technical feasibility of retrofit ADAS for trucks and buses only.

Retrofit ADAS | Technical feasibility and performance of retrofit ADAS
--- | ---
VIS-DET | Several retrofit Pedestrian & cyclist detection systems are available, and various technologies are used.

Professional installation and calibration required.

UN/ECE Regulation 151 can be applied also for testing retrofit

No significant functional or performance differences between factory-fitted and retrofit solutions.

**VIS-DET retrofitting is technically feasible**

### Bundling retrofit ADAS

Several retrofit ADAS products on the market provide multiple ADAS e.g. camera-based FCW, LDW, SLI etc. The bundling of several ADAS into one product does already exist in the market. Therefore, the **bundle to be included in the study is FCW-VEH&PCD + LDW + SLI** for passenger cars and light commercial vehicles.

In addition to the selected ADAS bundle, each of the listed retrofit ADAS are examined separately in the safety and cost-benefit assessments.
3.6 **Overview of retrofit systems on the market**

Table 7 includes a summary of the literature review of available retrofit ADAS products on the market today. For all ADAS, there are several manufacturers for retrofit ADAS devices. ADAS devices are available for several vehicle types and the price range varies a lot.

The current product prices are gathered by performing an extensive market search. In addition, the related (professional) installation costs for these ADAS are retrieved from the literature, interviews and expert judgement. A review of cost overviews of retrofitting ADAS that are currently available on the EU market, learns that on average there are quite a number of retrofit ADAS products on the market (see Table 7).

The available retrofit ADAS on the market are available in a broad price range. For instance, one could already buy a retrofit rear view camera or tyre pressure monitoring system for less than € 30. However, when considering ADAS with multiple functionalities (SLI, FCW and SLI) the purchase prices ranges from € 512 to € 950. This also holds for turning assistant systems for heavy vehicles (VIS-DET), where the prices range from € 470 to € 1,850. Overall the market prices range between € 20 and € 1,850, but the bandwidth per individual ADAS (and the manufacturer) differ substantially.

**Table 7. Purchases cost estimation for retrofit ADAS (based upon market prices) and approximation of installation time and costs for retrofitting ADAS**

<table>
<thead>
<tr>
<th>ADAS</th>
<th>Purchase costs (range)</th>
<th>Installation time (see Table 31)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower estimate</td>
<td>Higher estimate</td>
<td></td>
</tr>
<tr>
<td>FCW</td>
<td>€ 53</td>
<td>€ 950</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>LDW</td>
<td>€ 53</td>
<td>€ 950</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>SLI</td>
<td>€ 72</td>
<td>€ 542</td>
<td>0.5 hours</td>
</tr>
<tr>
<td>Bundle:</td>
<td>€ 512</td>
<td>€ 950</td>
<td>2 hours</td>
</tr>
<tr>
<td>FCW, LDW and SLI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDR-ADR</td>
<td>€ 180</td>
<td>€ 706</td>
<td>0.5 hours</td>
</tr>
<tr>
<td>REV</td>
<td>€ 20</td>
<td>€ 117</td>
<td>Professional installation €130</td>
</tr>
<tr>
<td>TPM</td>
<td>€ 24</td>
<td>€ 218</td>
<td>Professional installation €150</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>€ 470</td>
<td>€ 1,850</td>
<td>3.75 hours</td>
</tr>
<tr>
<td>eCall</td>
<td>€ 80</td>
<td>€ 270</td>
<td>0.5 hours</td>
</tr>
</tbody>
</table>

1. [https://www.mobileye.com/uk/fleets/products/mobileye-6-collision-avoidance-system/](https://www.mobileye.com/uk/fleets/products/mobileye-6-collision-avoidance-system/)
3. [http://plk.co.kr/product/dash-cam](http://plk.co.kr/product/dash-cam)
5. Amazon, Product name: Power Acoustik DVALT Lane Departure, Front Collision Warning System with DVR
7. [https://www.amazon.co.uk/Snooper-My-Speed-XL-Camera-Warning/dp/B01HHH2K74](https://www.amazon.co.uk/Snooper-My-Speed-XL-Camera-Warning/dp/B01HHH2K74)
8. [https://www.rearviewsafety.com/driver-fatigue-systems.html](https://www.rearviewsafety.com/driver-fatigue-systems.html/)

---

February 2020 - 31
Study on the feasibility, costs and benefits of retrofitting ADAS to improve road safety

11. https://www.parkingsensors.co.uk/page/fitting-options
15. https://www.amazon.co.uk/Sairis-External-Valve-cap-Pressure-Monitor/dp/B07MRF574X/
17. https://www.bowerspartsonline.co.uk/brands/brigade-electronics/brigade-ss4000w-
sidescan-ultrasonic-sensor-detection-system-vehicle-turning-left-cyclist-warning-kit
18. https://www.wuellhorst-fahrzeugbau.de/abbiegeassistent/
system
4  BASELINE SCENARIO

In this section, the ‘baseline’ for the impact assessment is discussed. The baseline (or reference) scenario (PO0) is the counterfactual scenario without any additional policies that would support and promote retrofit ADAS. The cost-benefit analysis (CBA) will assess the costs and benefits of promoting measures to stimulate voluntary retrofitting and the costs and benefits of mandating retrofitting against the baseline scenario.

The following sections describe the methodology applied to develop the baseline scenario and the resulting baseline scenario to which two policy scenarios will be compared.

4.1  Methodology

The baseline is developed on the basis of three steps. In the first step, the development of the EU fleet is determined. This development is broken down into different age categories, number of new vehicles and vehicles leaving the market. This step aids in constructing the baseline, as the number of vehicles eligible for retrofitting is assessed.

The second step is to assess the penetration rate of ADAS in the EU vehicle fleet. This step consists of an assessment of the current penetration rate, and the assessment of the most likely development of the penetration rate of factory-fitted ADAS. During the evaluation period (the period for which costs and benefits are assessed), the number of vehicles that will have factory-fitted ADAS fitted is expected to rise substantially, as Regulation (EU) 2019/2144 requires that all new vehicles are fitted with ADAS in June 2024 (for newly approved types, this date is set at June 2022).

The final step is to assess the (autonomous) development of retrofitting. At this moment there are already companies selling aftermarket ADAS on the European market. This indicates that there is a demand for retrofitting.

Together, these steps result into the baseline; the number of ‘retrofittable’ vehicles. Not every vehicle is eligible for retrofitting, as a share of the fleet will be already factory-fitted with ADAS. For example, retrofitting a vehicle with a Lane Departure Warning system if this vehicle has an Emergency Lane-keeping system factory-fitted would not yield an additional safety benefit. Therefore, vehicles with factory-fitted ADAS installed are not affected by measures stimulating retrofitting.

Essentially, promoting or mandating retrofitting is speeding up an already ongoing development since all new vehicles are already mandated to have ADAS factory-fitted in June 2024. Therefore, the penetration rate of ADAS in the EU vehicle fleet will (autonomously) converge to 100%.

The policy options, costs and benefits are only applicable to vehicles without factory-fitted ADAS installed. Vehicles with the selected ADAS already factory-fitted are not included in the scope of the CBA.

4.2  Development of the EU fleet

The development of the EU fleet by age category is shown in Table 8.
Table 8. Development of the EU fleet (to age category)\(^{10}\) \(\times 1000.\)

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Passenger cars</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–4 years</td>
<td>254,542</td>
<td>265,427</td>
<td>271,843</td>
<td>277,590</td>
<td>290,495</td>
<td>300,394</td>
<td>307,828</td>
<td>314,730</td>
</tr>
<tr>
<td>4–9 years</td>
<td>102,904</td>
<td>68,547</td>
<td>83,817</td>
<td>88,629</td>
<td>92,140</td>
<td>94,653</td>
<td>98,510</td>
<td>101,362</td>
</tr>
<tr>
<td>9–14 years</td>
<td>49,023</td>
<td>80,390</td>
<td>51,433</td>
<td>61,879</td>
<td>64,211</td>
<td>66,656</td>
<td>66,617</td>
<td>69,435</td>
</tr>
<tr>
<td>14–19 years</td>
<td>28,278</td>
<td>25,331</td>
<td>39,781</td>
<td>22,581</td>
<td>26,411</td>
<td>26,649</td>
<td>26,785</td>
<td>25,744</td>
</tr>
<tr>
<td><strong>Buses and coaches</strong></td>
<td>906</td>
<td>979</td>
<td>1,017</td>
<td>1,037</td>
<td>1,055</td>
<td>1,086</td>
<td>1,105</td>
<td>1,120</td>
</tr>
<tr>
<td>0–4 years</td>
<td>309</td>
<td>317</td>
<td>343</td>
<td>364</td>
<td>344</td>
<td>361</td>
<td>369</td>
<td>373</td>
</tr>
<tr>
<td>4–9 years</td>
<td>344</td>
<td>279</td>
<td>285</td>
<td>309</td>
<td>328</td>
<td>310</td>
<td>326</td>
<td>333</td>
</tr>
<tr>
<td>9–14 years</td>
<td>165</td>
<td>283</td>
<td>233</td>
<td>234</td>
<td>256</td>
<td>274</td>
<td>258</td>
<td>271</td>
</tr>
<tr>
<td>14–19 years</td>
<td>88</td>
<td>100</td>
<td>155</td>
<td>130</td>
<td>127</td>
<td>141</td>
<td>153</td>
<td>142</td>
</tr>
<tr>
<td><strong>Light comm. vehicles</strong></td>
<td>29,646</td>
<td>30,878</td>
<td>32,004</td>
<td>33,570</td>
<td>35,198</td>
<td>36,514</td>
<td>37,442</td>
<td>38,352</td>
</tr>
<tr>
<td>0–4 years</td>
<td>9,811</td>
<td>10,714</td>
<td>11,766</td>
<td>12,153</td>
<td>12,283</td>
<td>12,311</td>
<td>13,016</td>
<td>13,357</td>
</tr>
<tr>
<td>4–9 years</td>
<td>9,786</td>
<td>8,730</td>
<td>9,549</td>
<td>10,504</td>
<td>10,849</td>
<td>10,964</td>
<td>11,441</td>
<td>11,623</td>
</tr>
<tr>
<td>9–14 years</td>
<td>7,166</td>
<td>7,911</td>
<td>6,948</td>
<td>7,649</td>
<td>8,462</td>
<td>8,746</td>
<td>8,818</td>
<td>9,218</td>
</tr>
<tr>
<td>14–19 years</td>
<td>2,883</td>
<td>3,524</td>
<td>3,740</td>
<td>3,264</td>
<td>3,604</td>
<td>3,992</td>
<td>4,167</td>
<td>4,154</td>
</tr>
<tr>
<td><strong>Heavy goods vehicles</strong></td>
<td>7,013</td>
<td>7,828</td>
<td>8,357</td>
<td>8,776</td>
<td>9,332</td>
<td>9,847</td>
<td>10,208</td>
<td>10,492</td>
</tr>
<tr>
<td>0–4 years</td>
<td>2,566</td>
<td>2,451</td>
<td>2,677</td>
<td>2,923</td>
<td>3,132</td>
<td>3,120</td>
<td>3,178</td>
<td>3,335</td>
</tr>
<tr>
<td>4–9 years</td>
<td>2,394</td>
<td>2,474</td>
<td>2,364</td>
<td>2,579</td>
<td>2,819</td>
<td>3,019</td>
<td>3,007</td>
<td>3,063</td>
</tr>
<tr>
<td>9–14 years</td>
<td>1,351</td>
<td>2,114</td>
<td>2,163</td>
<td>2,084</td>
<td>2,248</td>
<td>2,492</td>
<td>2,650</td>
<td>2,643</td>
</tr>
<tr>
<td>14–19 years</td>
<td>703</td>
<td>790</td>
<td>1,154</td>
<td>1,190</td>
<td>1,132</td>
<td>1,217</td>
<td>1,327</td>
<td>1,451</td>
</tr>
</tbody>
</table>

Source: Baseline scenario, PRIMES-TREMOVE Transport Model (ICCS-E3MLab).

From Table 8, the number of new vehicles (over a five-year period) can be retrieved. After all, vehicles within the age category of 0–4 years in 2020 did not exist prior to 2015 and are thereby considered to be new vehicles in the European vehicle fleet. In addition to the number of new vehicles, the overall number of vehicles leaving the EU fleet can be deducted based on the PRIMES-TREMOVE model. Vehicles, with an age from 0 to 20 years, are leaving the market for several reasons.

First of all, the PRIMES model obtains no information on vehicles beyond the age category of 14 to 19 years. Thereby, the number of vehicles with an age of over 20 years can be retrieved quite easily; all vehicles within the age category of 14–19 years in 2015 left the market in 2020. As a result, vehicles with an age over 20 years are not included in the study as the PRIMES-TREMOVE transport model offers no information on the development of vehicles in this age category.

Secondly, there are also a number of vehicles within one of the age categories that are leaving the market due to several reasons. For instance, vehicles that have gone total loss or have been sold on the second hand market outside the EU. The number of vehicles that are leaving the market can be retrieved by determining the difference of the fleet size for the different age categories. If no vehicles would leave the market all vehicles in the age category of 0–4 years in 2015 have shifted to the age category of 4–9 years in 2020. Although, the number of vehicles in the age category of 4–9 years

\(^{10}\) Numbers for 2010 are not shown in order to ensure readability of Table 8. In the calculations, these numbers have been used.
2020 appeared to be lower than the number of vehicles in the age category of 0–4 years, which indicates that some vehicles have left the market.

The number of vehicles leaving the market (decomposed into four age categories) is presented in Table 9.

<table>
<thead>
<tr>
<th>Table 9. Vehicles leaving the market (to age category) × 1000.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Years</strong></td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td><strong>Passenger cars</strong></td>
</tr>
<tr>
<td>0–4 years</td>
</tr>
<tr>
<td>4–9 years</td>
</tr>
<tr>
<td>9–14 years</td>
</tr>
<tr>
<td>14–19 years</td>
</tr>
<tr>
<td><strong>Buses and coaches</strong></td>
</tr>
<tr>
<td>0–4 years</td>
</tr>
<tr>
<td>4–9 years</td>
</tr>
<tr>
<td>9–14 years</td>
</tr>
<tr>
<td>14–19 years</td>
</tr>
<tr>
<td><strong>Light comm. vehicles</strong></td>
</tr>
<tr>
<td>0–4 years</td>
</tr>
<tr>
<td>4–9 years</td>
</tr>
<tr>
<td>9–14 years</td>
</tr>
<tr>
<td>14–19 years</td>
</tr>
<tr>
<td><strong>Heavy goods vehicles</strong></td>
</tr>
<tr>
<td>0–4 years</td>
</tr>
<tr>
<td>4–9 years</td>
</tr>
<tr>
<td>9–14 years</td>
</tr>
<tr>
<td>14–19 years</td>
</tr>
</tbody>
</table>

Source: Baseline scenario, PRIMES-TREMOVE Transport Model (ICCS-E3MLab).

By making interpolations, the development of the fleet is retrieved on a yearly basis (instead of over a 5-year period).

### 4.3 Penetration rate for factory-fitted ADAS

The most relevant development of the penetration rate is based on the voluntary uptake in SWD/2018/190, based on none (0%), medium (40%) or high (80%) and a full voluntary implementation year. The validity of the assessed uptake has been triangulated by using additional sources; such as the market report of Frost & Sullivan (2018). Annex A presents the historic penetration rates that have been used.

The assessed penetration rate for factory fitted systems in 2025 is presented in Table 10.
Table 10. Penetration rate assessment of factory-fitted ADAS for 2025.

<table>
<thead>
<tr>
<th>Penetration rate factory-fitted ADAS</th>
<th>Passenger cars</th>
<th>Light commercial vehicles</th>
<th>Buses and coaches</th>
<th>Heavy goods vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCW-VEH</td>
<td>5%</td>
<td>37%</td>
<td>3%</td>
<td>36%</td>
</tr>
<tr>
<td>FCW-PCD</td>
<td>5%</td>
<td>37%</td>
<td>3%</td>
<td>36%</td>
</tr>
<tr>
<td>LDW</td>
<td>10%</td>
<td>38%</td>
<td>2%</td>
<td>26%</td>
</tr>
<tr>
<td>SLI</td>
<td>3%</td>
<td>17%</td>
<td>1%</td>
<td>14%</td>
</tr>
<tr>
<td>DDR</td>
<td>4%</td>
<td>30%</td>
<td>2%</td>
<td>25%</td>
</tr>
<tr>
<td>REV</td>
<td>16%</td>
<td>37%</td>
<td>4%</td>
<td>27%</td>
</tr>
<tr>
<td>TPM</td>
<td>43%</td>
<td>77%</td>
<td>2%</td>
<td>17%</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>Not applicable</td>
<td></td>
<td>&lt;1%</td>
<td>15%</td>
</tr>
</tbody>
</table>

4.4 Autonomous development of retrofit ADAS in the vehicle fleet

In addition to the development of factory-fitted ADAS in the EU vehicle fleet, autonomous development of retrofit ADAS should also be considered in order to establish overall penetration of ADAS in the vehicle fleet.

The following sections provide an overview of ongoing policies and initiatives to promote (retro)fitting and assess the of autonomous uptake of retrofit ADAS in the European vehicle fleet.

In order to assess how the uptake of retrofit ADAS could develop, an review is provided of ongoing initiatives to promote the uptake of retrofit ADAS. The following measures aimed at stimulating the retrofit ADAS are discussed:

- Awareness raising measures
- Financial incentives
- Public procurement requirements
- Urban vehicle access regulations (UVAR)

4.4.1 Current penetration of retrofit ADAS

While there are various reports that estimate the penetration rate of factory-fitted ADAS in the vehicle fleet in Europe, no sources have been found that assess the uptake of retrofit ADAS in the European fleet.

By combining the information from various ADAS market reports (see annex A), the current penetration of retrofit ADAS in the total EU vehicle fleet is assessed at approximately 0.2-0.4 percent.

4.4.2 Awareness raising measures

A (voluntary) measure to promote the uptake of retrofitting ADAS for existing vehicles would be to impose awareness raising measures. A lacking understanding of the expected safety or economic benefits, could be the reason that the adoption of retrofitting ADAS is increasing so slowly.

Practical example 1: ADAS Covenant in the Netherlands

In the Netherlands recent developments have been undertaken to support ADAS implementation. Multiple actors (e.g. OEMs, insurance companies, training facilities) signed an agreement to stimulate usage of ADAS, and all associated actors had to indicate practical steps how to enhance ADAS uptake. The main aim of the agreement is to increase safe usage of ADAS by 20% in the coming 3 years, which is to be reached.
by striving for three objectives: stimulating development, raising awareness and stimulating the purchase of ADAS. Additionally, by raising awareness with professional user organizations, there could be more understanding of the expected benefits. Sharing the expected safety and economic benefits could increase the voluntary uptake of retrofitting vehicles with ADAS.

**Practical example 2: Road Safety Campaigns**

The first example (and older example) of an effective road safety campaign is the BOB concept. The Belgium government introduced this concept to encourage people to stay sober and drive friends or relatives home. In 2001, the Netherlands picked up this concept. The campaign is repeated once annually, and consists of commercials on radio, TV and billboards. In addition, during alcohol tests, sober drivers are rewarded (e.g. with a BOB key chain). The BOB campaign has proven itself to be very effective for road safety improvement. Around two-thirds of Dutch drivers take precautions and are arranging a so-called BOB driver\(^\text{11}\) (van Kalmthout, 2016); the designated person that will not consume alcohol that evening.

On a pan-European scale, a number of road safety campaigns have been issued in the last couple of years.

- UK: THINK! Drink Drive Campaign (Department of Transport, 2014)
- Ireland: Anti-speeding campaign (Fitzgerald, 2017)
- Ireland: Driver Distraction Campaign (Fitzgerald, 2017)
- Czech Republic: Think or you’ll pay! (Stojanová & Blašková, 2018)

According to an evaluation of media campaigns in the Netherlands (Rijksoverheid, 2018), the number of campaigns and their associated costs are displayed. The associated cost of these campaigns will be explained in detail in section 5.2, costs of voluntary measures.

### 4.4.3 Financial incentives

There is vast experience concerning the use of financial incentives in the form of subsidies or tax incentives in Member States that influence vehicle fleet characteristics.

Such financial incentives can also serve as a means to reduce the cost of retrofitting safety systems for vehicle users, resulting in an increased purchase and installation of such systems. Tax incentives covers a broad scope of measures. For example, a Member State could provide favorable tax liability for employees that choose to retrofit their company car with ADAS. But a Member State could also offer VAT benefits to reduce the costs of retrofit products.

Another incentive to promote retrofit ADAS would be the provision of subsidies by the government for individual vehicle owners or fleet owners. A subsidy can be considered a support mechanism from the government or other non-commercial organization used to encourage activities with positive effects to the public. In this case, the subsidy would be used to make retrofitting vehicles with ADAS financially more attractive. Therefore, the intent to purchase or willingness to pay for them rises, potentially increasing the uptake of retrofit ADAS.

Although the use of financial incentives can be considered common to promote proliferation of ‘clean vehicles’ in the EU fleet, only a very limited number of examples from practice have been found where financial incentives are used to encourage vehicle owners to purchase (retrofit) ADAS.

---

\(^\text{11}\) The abbreviation of BOB is ‘consciously sober driver’
Practical example 3: Funding programme for turn assist in Germany

The German Ministry of Transport wants to decrease the number accidents of trucks with cyclist and pedestrians through the uptake of blind spot detection systems. Therefore, the German Ministry of Transport invested five million euro in 2019 to promote blind spot warning systems in heavy goods vehicles, called Abbiegeassistensystemen (BMVI, 2019a). The aim of this voluntary measure is to advocate the use of blind spot detection systems in HGVs. This measure compensated 80 percent of the purchase value of the new system, to a maximum of 1500 euro. (Fietsberaad, 2019).

With support from the program, 3,900 trucks have been retrofitted with the respective ADAS (Finke, 2019). The success of the campaign resulted in a doubling of the funding sum, so the expected number of applicants will double to 7,800 (BMVI, 2019b).

Practical example 4: Flemish subsidies

In 2017, the Flemish government provided a subsidy with an annual budget of 36 million euro to support companies willing to make their trucks and trailers safer and less polluting (Verhoeven, 2018). Each company was offered a limited budget of €100,000 to invest in automatic braking, soot filters, alcohol locks, cameras and blind spot detection systems. The subsidy was capped at 80% of the purchasing price, with a maximum of € 3 000 per vehicle. All vehicles with a Belgian license plate were eligible for this subsidy. Interest in this subsidy was found to be remarkably low, although the number of applicants in 2018 increased slightly. Around € 16 million subsidy was requested in 2017, and around € 32 million was granted in 2018 (Verhoeven, 2018).

Practical example 5: Israel funding scheme

In Israel, the Ministry of Transport together with the Tax Authority granted tax incentives for vehicles to equip safety systems. Since August 2013, car buyers receive a tax reduction from the Israel Tax Authority when purchasing a Mobileye ADAS. The size of the tax reduction is dependent on how many ADAS functions they offer in a car, measured on a scale of zero to eight (Israeli Tax Authority, 2017). Thereby an incentive was created for manufacturers to promote ADAS. The tax scheme has proven to be efficient, and e.g. in the first three quarters of 2017, 75% of all imported vehicles had lane departure control and 60% of all newly registered vehicles had pedestrian detection (Israeli Tax Authority, 2017).

4.4.4 Insurance policies (or insurance premiums)

There are several insurance companies providing policies which consider the installation of specific safety equipment to offer reduced premiums. There are already examples where insurers offer a 20% premium to users that install certain ADAS. This is especially applicable to the installation of black boxes (EDR-like devices). Moreover, some insurers cover the cost for users to install the device. There seems to be a (positive) business case for insurers that offer reduced premiums in return for vehicle users to install safety-related systems. The next section will outline a few examples of insurance policies where reduced premiums are put into practice.

Practical example 6: ADAS Risk Score

According to Swiss Re (2018) and HERE, factory-fitted ADAS technology potentially reduces accidents up to 25%. In that respect, the car insurance premiums decrease with around USD 20 billion by 2020. For insurers to make these technologies a part of their risk pricing models, they need to collaborate with manufacturers. Therefore, Swiss Re, in cooperation with BMW, have developed an ADAS risk score algorithm. This system uses different datasets (per individual vehicle) in order to assess the risks. Finally, the insurer is able to consider the ADAS risk score into their own rating model. Therefore,
insurers increasingly consider the vehicle a person is driving more than the person driving the vehicle (BMW Group, 2018).

**Practical example 7: Insurance discount with ACI-SARA**

SARA Assicurazioni, an Italian insurance company, and Automobile Club Italia reached an agreement with a manufacturer of retrofit ADAS devices (Mobileye). They offer 20% discount on the liability price when they choose to install an ADAS anti-collision device (FleetEurope, 2018). Recently, also American insurance companies (AIG and Munich Reinsurance America) have also adopted similar schemes. All these schemes however have been put in place only recently, and the effects of these schemes are still to be determined.

It is noted although there are examples of insurance companies that provide insurance premium discounts, it should not be taken as common practice. For example, Reuters (Bellon, 2019) reported US insurers are not prepared to offer discounts for vehicles fitted with ADAS due to a lack of data to back up claims by auto manufacturers of reduced risk.

**4.4.5 Public procurement requirements**

The third financial incentive to increase the uptake of retrofit ADAS would be to impose certain requirements for public procurement. Requiring an increased safety level of the public sector or public service vehicles may be a way to support retrofitting vehicles.

**Practical example 8: Blind spot technology and ISA in London**

The Transport Research Laboratory (TRL) tested together with Transport for London (TfL) ways to reduce the blind spot accidents involving heavy goods vehicles (HGVs). Despite the fact that only 4% of the miles traveled in London are HGV related, they are involved in 50% of the cyclist and 23% of the pedestrian fatalities. Therefore, they tested cameras, optical and radar detection for HGVs. From 2019 onwards, all new London buses are mandated to include the following requirements: high-grip flooring, automatic speed limits, more blind-spot mirrors and reversed cameras and special warning indicators for drivers. All vehicles obtain a star rating, corresponding to the quality of direct vision from the HGV cabin. In case the HGV does not have the required direct vision, it has to be equipped with a “Safe System”, which improves the visibility of VRUs in the proximity of the vehicle. VIS-DET is part of the Safety System. (Transport for London, 2018). After successful trials with a mandatory retrofit on buses, Transport for London requires all new buses to be fitted with ISA (ETSC, 2018). Generally, feedback from the drivers is positive, although there were some issues during low demand traffic (ETSC, 2018). By the end of 2018, 500 buses are fitted and the whole fleet should be equipped with ISA by 2028.

**Practical example 9: Pilot Barcelona City Council**

Barcelona City Council (2017) conducted a pilot study in which buses where equipped with an advanced collision avoidance system. First, roughly 40 buses were equipped with ADAS to determine the effectiveness of these systems. The aim of the Barcelona City Council is to make it mandatory for all new municipal vehicles to be equipped with ADAS.

**4.4.6 Urban vehicle access regulations (UVAR)**

Throughout Europe a few initiatives have been implemented. Two of these examples are discussed, London and Vienna.
London

In 2016 the Mayor of London, Sadiq Khan, launched the Direct Vision Standard (DVS) and safety permit for heavy goods vehicles (HGVs). From 26th October 2020 all HGVs over 12 tonnes gross vehicle weight entering and operating in Greater London will need to hold a valid HGV Safety Permit.

HGV operators need to apply for a permit for their vehicles. They will be granted a permit if the vehicle meets the minimum rating provided in the DVS. The DVS rates how much an HGV driver can see directly through their cab windows. This indicates the level of risk to vulnerable road users, such as people walking and cycling, near the vehicle.

A vehicle can have a rating of zero stars (the lowest rating, with poor direct vision) up to five stars (the highest rating with excellent direct vision). HGV rated one to five stars, can apply for a permit without further requirements.

However, HGV rated zero stars are required to fit the vehicle with Safe System improvements, which consists of Class V and VI mirrors; a fully operational camera monitoring system; a sensor system with driver alerts; audible vehicle manoeuvring warning for left turns (or right turns if the vehicle is left-hand drive) and warning signage to warn road users of intended manoeuvres; and side-underrun protection.

Vehicles rated with less than three stars will receive a permit until in October 2024. After this date these vehicle will be required to (retro)fit the vehicle with additional Safe System improvements. The Safe System will be reviewed and consulted on in 2022 and will take into account any additional technology or safety equipment not currently available. Three, four and five-star permits will be valid for 10 years.

The scheme will be enforced from 26 October 2020 across Greater London, 24 hours a day, seven days a week. Operators driving within Greater London without a valid permit after that date may receive a penalty charge notice of up to £550. Enforcement will be carried out by comparing the TfL database of vehicle registrations with valid permits with the automatic number plate recognition (ANPR) camera captures of vehicles entering London.

Vienna

The death of a nine-year-old boy who was killed by a truck in a tragic accident on his way to school in January 2019, triggered a national debate on mandating turn-off assistants for trucks (N2 and N3).

Although public support for such a mandate was expressed in a petition signed by some 75,000 people and various stakeholder organisations, including several motorists and road safety organisations, Austria’s federal government decided not to mandate a requirement for a turn-off assistant in trucks.

With no "uniform criteria for retrofittable systems" in place, the national government wanted to wait until the technical specifications of the EU are in place, so that there are no unnecessary investments and assistants have to be exchanged within a few years.

Instead of a mandate, it was decided on a number of short-term measures to mitigate unsafe traffic situations related to low visibility of vulnerable road users posed by the 'blind spot' of trucks when turning. To promote voluntary (retro)fitting of trucks with turn-off assistants, a national subsidy scheme has been launched in September 2019. A total of one million euro has been made available by the federal government to support companies and co-finance part of the system and installation costs of turning assistance systems when retrofitting vehicles with these systems as well as for designated equipment when purchasing new vehicles. The subsidy can cover up to 25 percent or
a maximum of € 900 of the costs per truck, with a maximum of five vehicles per company.

In addition, focus will be placed on raising awareness. The ministry wants to provide five million euro for training and further education of professional drivers. An information campaign on the risks related to blind spot will be started to raise awareness among vulnerable groups such as older road users and children.

Finally, there is a possibility for municipalities to introduce a right-turn ban on trucks at specific intersection are considered unsafe. In these cases a relevant ordinance is to be provided by the municipality.

The City of Vienna announced that it will use this option to amendment to the Highway Code and introduce a right-turn ban for trucks over 7.5 tonnes without turn-off assistance throughout large parts of the urban area. The ban should come into effect for all vehicles - regardless whether they are registered in the city or elsewhere - by spring 2020, with a transitional period of one year.

The regulation will also affect 300–500 vehicles owned by the municipality. The city plans to retrofit these vehicles, while also introducing a public procurement requirement for turn-assist in all relevant N2 and N3 vehicles acquired.

4.4.7 Conclusion on autonomous development of retrofitting

At this moment, a range of initiatives to stimulate the uptake of (retrofitted) ADAS is put into place. However, most initiatives have only been implemented recently and the majority is primarily focusing on stimulating the uptake of factory-fitted ADAS. As it is likely that Regulation (EU) 2019/2144 has the most significant impact on the penetration rate of ADAS, there is no reason to further augment our autonomous penetration rate development of factory-fitted vehicles (described in Section 4.3).

There are currently two initiatives that also target retrofit ADAS, namely the incentive schemes in Belgium and Germany (practical examples 3 and 4). Based on the results obtained in these countries, the (EU) penetration rate of retrofitting is assessed to be 0.2% for heavy good vehicles (N2 & N3). This assessment is also adopted for M1, N1 and M2 & M3 vehicles. This means that the current number of vehicles retrofitted is expected to be 0.2%.

The autonomous development of retrofitting (the number of vehicle owners that decide to retrofit their vehicle independent of EU intervention) is estimated to grow with 4% a year (up to 0.5% in 2040). This assessment is based on WiseGuyReports (2018) and McKinsey (2016a), who expect the market for automotive aftermarket devices to grow with roughly 4% (3.9%) a year up till 2030.

These numbers were also brought forward during the stakeholder meetings and several interviews and are not contest. Neither was additional information provided.

4.5 Availability of single ADAS-functionality retrofit products

As can be seen in Table 10, the penetration rate of different systems differs substantially. This poses a methodological problem in our cost-benefit assessment, since it is no possible to tell how many ADAS are installed in a single vehicle. Theoretically, it could be the case that 17% of the fleet has FCW-PCD installed, but that only a very limited number of these vehicles have TPM installed.

This complicates the analysis, as one has to assess whether a vehicle with only a few ADAS factory-fitted is able to be retrofitted with other ADAS. This would mean that for example a second camera has to be installed. Moreover, as is mentioned in Table 5, there are currently no (single) retrofit products for LDW and FCW. This means that a
retrofit product with a LDW feature automatically also has another ADAS functionality. However, if this other ADAS functionality is already factory-fitted in the vehicle, the vehicle will be installed with both a factory-fitting and a retrofit product. This is an undesirable situation according to stakeholders.

In order to tackle this issue in our CBA, it is assumed that vehicles with either LDW/LKA, FCW/AEB, SLI/ISA factory-fitted are not eligible for retrofitting LDW, FCW and SLI.

4.6 Conclusions

Even in a baseline scenario, the penetration rate of Advanced Driver Assistance Systems (ADAS) is expected to increase. The first reason for this is that OEMs (even without policy intervention) offer ADAS as an option when vehicles are purchased. As will be discussed in Chapter 6, vehicle drivers that are experienced with ADAS are more likely to purchase these options. SWD/2018/190, describes the voluntary uptake (without additional policy measures) of various driver assistance systems. Since the GSR update (Regulation (EU) 2019/2144) is adopted, the penetration rate of ADAS will increase further. Next to an increase in the penetration rate as a result of factory-fitted ADAS deployment, the penetration rate of ADAS will also increase as a result of retrofitting. However, the number of vehicles equipped with retrofit ADAS is expected to remain rather small in the baseline.

In our cost-benefit assessment, passenger cars and light commercial vehicles older than 15 years are exempted from our analysis. It is expected that owners do not retrofit their vehicle voluntarily as they have no economic incentive to do so. In case of stipulating mandatory retrofitting vehicles, owners are more likely to purchase a new vehicle with ADAS factory-fitted than to retrofit the old vehicle. The following number of 'retrofittable' vehicles is presented in Table 11.

Besides the baseline development of ADAS uptake, an assessment of the autonomous development of road casualties (fatalities and injuries) is made. The methodology behind this assessment and the resulting numbers are presented in Annex D.
Table 11. Number of retrofittable vehicles in 2025 (in thousands of vehicles).

<table>
<thead>
<tr>
<th>Vehicle category</th>
<th>ADAS</th>
<th>(A) No. of vehicles</th>
<th>(B)(^1) No. of vehicles with factory-fitted ADAS</th>
<th>(C) No. of exempted vehicles (&gt;15 years)</th>
<th>(D=A-B-C) No. of retrofittable vehicles</th>
<th>(D/A) % of retrofittable vehicles in fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fleet size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger cars (M1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDR</td>
<td>271,843</td>
<td>104,516</td>
<td>39,781</td>
<td>151,189</td>
<td>56%</td>
<td></td>
</tr>
<tr>
<td>FCW-PCD</td>
<td>271,843</td>
<td>104,516</td>
<td>39,781</td>
<td>127,546</td>
<td>47%</td>
<td></td>
</tr>
<tr>
<td>FCW-VEH</td>
<td>271,843</td>
<td>104,516</td>
<td>39,781</td>
<td>127,546</td>
<td>47%</td>
<td></td>
</tr>
<tr>
<td>SLI</td>
<td>271,843</td>
<td>104,516</td>
<td>39,781</td>
<td>127,546</td>
<td>47%</td>
<td></td>
</tr>
<tr>
<td>LDW</td>
<td>271,843</td>
<td>104,516</td>
<td>39,781</td>
<td>127,546</td>
<td>47%</td>
<td></td>
</tr>
<tr>
<td>REV</td>
<td>271,843</td>
<td>100,717</td>
<td>39,781</td>
<td>131,345</td>
<td>48%</td>
<td></td>
</tr>
<tr>
<td>TPM</td>
<td>271,843</td>
<td>209,926</td>
<td>39,781</td>
<td>22,136</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>112 eCall</td>
<td>271,843</td>
<td>156,521</td>
<td>39,781</td>
<td>75,541</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td>Buses and coaches (M2&amp;M3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDR</td>
<td>1,017</td>
<td>729</td>
<td>288</td>
<td>784</td>
<td>77%</td>
<td></td>
</tr>
<tr>
<td>FCW-VEH</td>
<td>1,017</td>
<td>729</td>
<td>288</td>
<td>288</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td>SLI</td>
<td>1,017</td>
<td>729</td>
<td>288</td>
<td>288</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td>LDW</td>
<td>1,017</td>
<td>729</td>
<td>288</td>
<td>288</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td>REV</td>
<td>1,017</td>
<td>132</td>
<td>885</td>
<td>87%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPM</td>
<td>1,017</td>
<td>282</td>
<td>735</td>
<td>72%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIS-DET</td>
<td>1,017</td>
<td>133</td>
<td>884</td>
<td>87%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light commercial vehicles (N1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDR</td>
<td>32,004</td>
<td>11,680</td>
<td>3,740</td>
<td>16,584</td>
<td>52%</td>
<td></td>
</tr>
<tr>
<td>FCW-PCD</td>
<td>32,004</td>
<td>11,680</td>
<td>3,740</td>
<td>16,584</td>
<td>52%</td>
<td></td>
</tr>
<tr>
<td>FCW-VEH</td>
<td>32,004</td>
<td>11,680</td>
<td>3,740</td>
<td>16,584</td>
<td>52%</td>
<td></td>
</tr>
<tr>
<td>SLI</td>
<td>32,004</td>
<td>11,680</td>
<td>3,740</td>
<td>16,584</td>
<td>52%</td>
<td></td>
</tr>
<tr>
<td>LDW</td>
<td>32,004</td>
<td>11,680</td>
<td>3,740</td>
<td>16,584</td>
<td>52%</td>
<td></td>
</tr>
<tr>
<td>REV</td>
<td>32,004</td>
<td>8,761</td>
<td>3,740</td>
<td>19,503</td>
<td>61%</td>
<td></td>
</tr>
<tr>
<td>TPM</td>
<td>32,004</td>
<td>5,416</td>
<td>3,740</td>
<td>22,848</td>
<td>71%</td>
<td></td>
</tr>
<tr>
<td>112 eCall</td>
<td>32,004</td>
<td>18,576</td>
<td>3,740</td>
<td>9,688</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Heavy goods vehicles (N2&amp;N3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDR</td>
<td>8,357</td>
<td>1,833</td>
<td>6,524</td>
<td>78%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCW-VEH</td>
<td>8,357</td>
<td>5,958</td>
<td>2,399</td>
<td>29%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLI</td>
<td>8,357</td>
<td>5,958</td>
<td>2,399</td>
<td>29%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDW</td>
<td>8,357</td>
<td>5,958</td>
<td>2,399</td>
<td>29%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>REV</td>
<td>8,357</td>
<td>1,039</td>
<td>7,318</td>
<td>88%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPM</td>
<td>8,357</td>
<td>2,276</td>
<td>6,081</td>
<td>73%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIS-DET</td>
<td>8,357</td>
<td>1,045</td>
<td>7,312</td>
<td>87%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) The bold cells indicate that the highest penetration rate between LDW/LKA, FCW/AEB, SLI/ISA is used, because of the methodological issue posed in section 4.5. Although the actual penetration might be lower, still some vehicles will not be eligible as they have either LDW/LKA, FCW/AEB, SLI/ISA factory-fitted and for these no single ADAS-functionality product exist.
5 MEASURES STIMULATING UPTAKE OF RETROFITTING

As mentioned in Section 2.4, this report assesses two sets of policy measures, which could be introduced to promote further uptake of ADAS through retrofit ADAS. PO1 assesses the effects of voluntary measures that stimulate the uptake of retrofitting. PO2 assesses the effects of mandatory measures that stimulate the uptake of retrofitting. This chapter describes the content of both options in greater detail.

5.1 Voluntary measures (PO1)

In our CBA (which is presented in Chapter 6), a financial incentive and an awareness raising campaign (simultaneously) are considered. As can be deducted from section 4.4.1–4.4.6, evidence on the effectiveness of different measures is scarce and results differ per country. Based on some evidence-based hypothesis, it is attempted to come with an estimate on the effectiveness of voluntary measures.

The effectiveness of an awareness raising campaign can be deduced from a study performed by McKinsey (2016b). Researchers have conducted an online survey of more than 4,500 car buyers in four different countries (Germany, Japan, South Korea and the United States).

McKinsey finds that for a consumer decision, the following different process steps are outlined:

- All vehicle buyers;
- Awareness;
- Trial;
- Purchase;
- Intent to repurchase;

These process steps are offsets against transfer rates (percentage of buyers moving from one stage of the consumer decision journey to the next stage). The results are visualized in Figure 1.

![Figure 1. Transfer rates and process-step values in the consumer decision journey for advanced driver-assistance systems in selected countries, % (McKinsey, 2016b).](image)

Figure 1 shows that in Germany, 77% of all vehicle buyers are aware of the existence of ADAS. About 10% of all vehicle buyers in Germany has decided to purchase ADAS. Judging from the figure, it seems that unfamiliarity with ADAS is one of the major causes
that restricts the purchase of them. Theoretically, a proper awareness raising campaign has the ability to increase the awareness to a 100%. Following the process-step values of McKinsey (assuming an awareness of a 100 as a result of an awareness raising campaign), about 13% of all vehicle buyers would decide to install ADAS in their vehicle. Assuming the same effectiveness for retrofit ADAS, it is expected that an awareness raising campaign has the potential to increase the penetration rate of retrofit ADAS to grow with 3 percentage points.

Next to measures to increase the awareness of retrofit ADAS, a financial instrument to increase the uptake of retrofit ADAS is considered. As section 4.4 revealed, two financial instruments to stimulate ADAS uptake are currently in place in EU Member States (namely in Belgium and in Germany). The incentive scheme in Germany has proven to be very successful, as the number of subsidy requested exceeded the amount available. This means that it is hard to disentangle the true demand for this subsidy.

In the CBA, the effectiveness of the subsidy in Flanders (for which all Belgian HGV were eligible) is considered. The subsidy has resulted in a granted subsidy of around € 25 million for ADAS-like systems. The maximum amount was capped at € 3,000 per vehicle. The subsidy also covered expenditures on other systems, for example on systems decreasing greenhouse gas emissions. In total, the subsidy granted in 2017 and 2018 amounted € 48.5 million.

It is assumed that applicants have requested the full subsidy amount per vehicle (€ 3,000). If it is assumed that this amount is equally distributed across ADAS-like and non-ADAS like products, it is found that vehicle owners have been granted € 1,550 per vehicle to spend on ADAS-like products. If total amount granted for ADAS systems (€ 25 million) is divided by the assumed amount per vehicle (€1,550), it is expected that around 16,200 have fitted their HGV with ADAS as a result of this subsidy.

There are currently around 221,000 HGV vehicles registered in Belgium. This suggests that the subsidy has resulted in an increase uptake of 7.3% percentage points (over two years). The subsidy was thus able to increase the uptake with about 3.7 percentage points per year.

In our CBA, a one-year awareness raising campaign is modelled (increasing the uptake with 3 percentage points in one year) and a three-year subsidy program (increasing the uptake with 3.7 percentage points per year). The accompanying costs and benefits are described in Chapter 6.

5.2 **Mandatory measures (PO2)**

Besides voluntary measures, a second policy option is developed in which retrofitting is mandated. Based on stakeholder consultations, it is expected 2026 to be feasible to introduce mandatory fitment. This means that, from 1 January 2026, all vehicles that do not have the ADAS under consideration installed (either factory-fitted or retrofit) are mandated to retrofit their vehicle.

In order to offer some time to vehicle owners to do so, a 2-year grace period is assumed. This means that, in our CBA, vehicle owners are allowed to retrofit their vehicle by 31 December 2027 at the latest.

It is assumed that half of the retrofittable vehicle fleet will retrofit their vehicle in 2026, and the remaining half of the retrofittable fleet is retrofitted in 2027. All vehicle owners are assumed to abide the law, as is common practice in a CBA.

---

12 PRIMES-TREMOVE Transport Model
Stakeholders commented that the public acceptance for mandatory retrofitting would be very low. The societal costs of the limited acceptance are not included in the CBA analysis, as it is not possible to quantify or estimate these costs. However, it should be noted that this public acceptance is a great concern among stakeholders.

5.3 Exemptions

When considering measures (both voluntary and mandatory) to increase the uptake of ADAS by retrofitting, it is important to consider the residual value of the vehicle as soon as policy measures are put into place. Passenger cars lose between 15% and 30% of their value per year (depending on the brand and model) on average. This implies that after 15 years, the initial (purchasing) value of the car is reduced by 90–99%. Given an average purchasing price for passenger cars of around €30,000 (ICCT, 2018), this entails that the residual value of these cars is between €300 and €3,000. Since the price of retrofit devices is expected to be in this bandwidth, one cannot expect consumers to purchase such a car; they will either choose to replace their car earlier, or have no (economic) incentive to purchase the retrofit devices. The same reasoning applies to light commercial vehicles, for which the depreciation rate is even steeper.

For heavy good vehicles, buses and coaches, the same principle applies. However, (in general) the purchasing price is higher. The purchasing price for a heavy goods vehicle, a bus or a coach is around €150,000. This means that, after 15 years, the residual value of such a vehicle would still be between €1,500 and €15,000, which is higher than the price of retrofit devices. From an economic perspective, it still makes sense to purchase a retrofit device for a heavy goods vehicle of 15 years old.

Therefore, passenger cars and light commercial vehicles from 15 years and older are excluded from our analysis. It is expected that owners will not retrofit their vehicle voluntarily as they have no economic incentive to do so. In case of stipulating mandatory retrofitting vehicles, these owners are more likely to purchase a new vehicle with ADAS factory-fitted.

5.4 Effects on the penetration rate

The policy measures positively affect the uptake of the selected ADAS penetration in the vehicle fleet. The effect of the two different policy measures on the uptake of FCW is presented in Figure 2. This figure is meant to serve as an example and a visualization on how the penetration rate development looks like. For other ADAS/vehicle combinations, the figure would look slightly different as the baseline penetration (and hence the effects of the policy measures on the uptake) differ.

---

13 The depreciation rate declines with years; a 1-year old vehicle depreciates faster than a 10-year old vehicle.
14 Several sources, among which the Dutch tax agency, leasing companies and the American IRS
From Figure 2, it can be observed that the increase in the uptake is highest for the mandatory measures (the dotted line). What can also be noted is that the effect of the policy options on the penetration rate fades out as time progresses. For example, the effect of PO1 and PO2 on the penetration rate is equal in 2034 (whereas PO2 has higher impact on the penetration rate in earlier years).

The effect of the policy options on the penetration rate decreases over time, as the number of vehicles eligible for retrofitting decreases over time. Vehicles eligible for retrofitting gradually leave the market and are replaced by vehicles with factory-fitted ADAS as a result of Regulation (EU) 2019/2144. As mentioned in Chapter 4, these vehicles are not eligible for retrofitting. Hence, policy options stimulating the uptake of retrofitting have an effect on a decreasing share of the fleet. This means that the impact of the policy options decreases over time.

In the year 2041, both policy options have no effect on the penetration rate anymore. In this year, all vehicles in the EU fleet are factory-fitted with ADAS as a result of the Regulation (EU) 2019/2144. Retrofitted vehicles in the period 2026–2041 are replaced by factory-fitted vehicles. The policy options are thus most effective in the earlier years, as the number of retrofittable vehicles is highest. This is also reflected in Figure 2. This has an important consequence for the benefit (and cost development) over time, since they depend on the impact of different policy options on the penetration rate. Just as the penetration rate, costs and benefits are highest in the earlier years and decrease over time. In Figure 2, the costs and benefits are equal to zero in 2041 as the number of retrofittable vehicles decreases.

As already mentioned, Figure 2 only presents the penetration rate development for one specific ADAS/vehicle combination. The graph will look slightly different for other ADAS/vehicle combinations, mostly because of a different baseline assessment of the penetration rate of ADAS in the considered vehicle.
6 COST-BENEFIT ANALYSIS

In this Chapter, the results from the cost-benefit analysis are discussed. Section 6.1 offers a brief description of the evaluation period, the discount rate that has been adopted and how results of the CBA are presented.

Section 6.2 and 6.3 discusses all individual cost and benefit components in greater detail. Where applicable, the monetised assessments are provided.

Section 6.4 offers the results of the cost benefit analysis, in which the costs and benefits discussed in Section 6.2 and 6.3 are brought together. Finally, section 6.5 offers a sensitivity on some key inputs in the CBA.

Because some assessments made throughout this chapter are uncertain, most assessments (and the results) are presented in a bandwidth (low and high). The resulting CBA outcomes are a representation of the worst case scenario (with high costs and low benefits, assessment ‘high’) and the best case scenario (with low costs and high benefits, assessment ‘low’).

6.1 Evaluation period, discount rate and presentation of results

In this CBA, the effects are analysed over a period of 15 years, which is similar to the evaluation period used in SWD/2018/190. The period in this study starts in 2026, when the first policy measures are put into place (e.g. an awareness raising campaign and a subsidy scheme for policy option 1 and mandatory fitment in policy option 2) and runs for a period of 15 years. Hence, the evaluation period considered in our study is 2026–2041.

The discount rate is used to determine the present value of costs and benefits. The discount rate adopted in our study is the same as the discount rate that has been adopted by SWD/2018/190, namely 4.25%. This rate is in real terms, so without taking into account future inflation. This discount rate differs slightly from the prescribed discount rate in the Better Regulation Guidelines (Toolbox #61). The Better Regulation Guidelines state that a discount rate of 4% should be adopted. In order to ensure consistency with SWD/2018/190 the same discount rate is adopted. In a sensitivity analysis, the discount rate that is prescribed by the Better Regulation Guidelines is adopted.

The results of the CBA will be expressed in benefit-to-cost ratios (BCR). Using the discount rate, the present value of all costs and benefits is assessed. The BCR takes the present value of the benefits, and divides these by the costs. If the BCR exceeds 1, this means that the (present value of the) benefits are higher than the (present value of the) costs, and the measure is considered to be cost-effective.

Alternatively, one could have chosen to present the outcomes in the CBA in terms of the Net Present Value (NPV) or the Internal Rate of Return (IRR). The outcomes of the CBA are expressed in a BCR as this is also the way as the results are presented in SWD/2018/190.

6.2 Costs

The following costs are included in the CBA analysis:

- Initial purchase and installation costs
- Maintenance, periodic inspection and repair costs
- Campaign costs
- Subsidy costs
A brief cost description for the different costs elements, the methodology and the discounted costs that are used in the CBA are presented in the following sections.

6.2.1 Initial purchase and installation costs
The first cost component that is considered are the initial purchase costs for retrofitting ADAS and the associated installation costs. In order to ensure consistency with the purchase cost estimates of SWD/2018/190, we have adopted the same costs estimates.

However, these are not necessarily the costs that producers charge for retrofit devices that are currently on the market. However, it is found that the cost estimates of SWD/2018/190 are to a large extent in line with the bandwidth of prices for retrofit devices that are already on the market (see section 3.5). The main difference is that the bandwidth of the prices for retrofit products is larger than the bandwidth of the cost estimate in SWD/2018/190. The initial purchase and installation costs per retrofit ADAS included in the CBA are displayed Annex B, Table 31.

In a sensitivity analysis, the cost estimates for retrofit devices is included in the cost-benefit analysis to test the robustness of the CBA results for purchasing costs.

The cost estimates of SWD/2018/190 are corrected to account for aftermarket installation costs. It is assumed that aftermarket installation of ADAS is more expensive than in-factory installation and hence a ‘mark-up’ of the costs adopted in SWD/2018/190 is necessary.

These installation costs are retrieved by determining the (professional) installation time or costs of retrofitting devices that are currently on the market. Consequently, the hourly labour costs of a technician that is able to install (and/or inspect) the retrofit ADAS products is determined. Bovag (2019) estimates these hourly labour costs at around € 70 in the Netherlands. According to Eurostat (2019), the hourly wages in Europe are roughly 30% lower than in the Netherlands. The EU hourly labour costs are therefore estimated at € 49. The expected installation time or costs for retrofit ADAS are presented in Table 7.

Purchase price development

Once the autonomous uptake of retrofit ADAS in the vehicle fleet increases, real prices of these systems are expected to decline due to economies of scale and increased competition. In addition, the penetration rate is expected to increase as a result of policy options, which implies that real prices could further decline.

Although the consulted stakeholders are (unanimously) expecting prices for retrofit ADAS to reduce as the market (i.e. uptake) for these systems increases, it is found hard to estimate the magnitude of potential price reductions.

In the absence of a clear consensus on price development, this report assumes real prices will remain stable in the baseline scenario. Despite some initiatives in Member States to promote retrofit of certain type of ADAS for specific vehicle categories, the scale and scope of promotion remain to vary greatly among Member States. In cases where financial incentives to retrofit ADAS are provided, standards for eligible ADAS differ from scheme to scheme. The penetration grade in the fleet remains limited and the market fragmented.

---
16 For some ADAS, an assessment of the costs (in euro) was available. For these ADAS, the found assessments were used.
In the policy option where voluntary retrofitting is promoted, it is assumed prices will reduce by some 1.5 percent per year, following the introduction of the policy option.

In the policy option where retrofitting of ADAS is mandated, price reductions are assumed to be larger than in a policy scenario where only voluntary retrofitting is promoted. After all, a large market has been created. Standardisation and certification procedures are in place and harmonised across the EU. Mass production and competition between ADAS suppliers drive prices down. Retrofit ADAS prices are assumed to reduce by 30 percent in 2026 and then continue to reduce by 1.5 percent per year until the end of the evaluation period.

The (discounted) values of the purchase and installation costs (which serve as input for the CBA) are presented in Table 12.

Table 12. Discounted value of purchase and installation costs in PO1 (voluntary measures) and PO2 (mandatory measures) (in millions of €).

<table>
<thead>
<tr>
<th>Retrofit ADAS</th>
<th>PO1: Voluntary measures</th>
<th>PO2: Mandatory measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>FCW</td>
<td>€ 4,274</td>
<td>€ 5,471</td>
</tr>
<tr>
<td>LDW</td>
<td>€ 9,429</td>
<td>€ 10,546</td>
</tr>
<tr>
<td>SLI</td>
<td>€ 4,630</td>
<td>€ 5,906</td>
</tr>
<tr>
<td>Bundle (FCW, LDW, SLI)</td>
<td>€ 17,089</td>
<td>€ 20,680</td>
</tr>
<tr>
<td>DDR</td>
<td>€ 6,824</td>
<td>€ 9,936</td>
</tr>
<tr>
<td>REV</td>
<td>€ 6,087</td>
<td>€ 7,284</td>
</tr>
<tr>
<td>TPM</td>
<td>€ 8,107</td>
<td>€ 13,852</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>€ 397</td>
<td>€ 818</td>
</tr>
<tr>
<td>112 eCall</td>
<td>€ 4,026</td>
<td>€ 11,377</td>
</tr>
</tbody>
</table>

6.2.2 Maintenance, inspection and repair costs

The second cost component concerns costs to ensure that the ADAS functions properly after it has been retrofitted on a vehicle. Hence, this section discusses maintenance, inspection and repair costs.

Maintenance and periodic inspection

For proper functioning of retrofit ADAS and to secure the safety benefits, appropriate maintenance is required. Based on consultation of industry experts and stakeholders, it can be assumed retrofit ADAS require limited maintenance. The impact on overall vehicle maintenance costs is limited.

Without the occurrence of incidents that limit the functioning of retrofit ADAS, an annual check to ensure cameras and sensors are correctly calibrated would be sufficient to ensure appropriate functioning of systems. Such checks could be performed at the same time vehicles undergo periodic roadworthiness tests (i.e. PTI).

It is found that including an inspection regarding the functioning of a retrofit ADAS device would increase the inspection costs with of € 20 – 30 per inspection. The average

---

17 The percentage is estimated based on an average price development of technical equipment sectors (see Annex E).
inspection rate for a vehicle is once per 1.5 years\(^\text{18}\), bringing the yearly costs at around € 15 – 25 per retrofitted vehicle.

The number of retrofittable vehicles that needs to have a yearly ADAS inspection is retrieved from the penetration rate assessment in the baseline scenario. In case of voluntary measures (PO1) the penetration rate of retrofitted vehicles is substantially lower than when considering mandatory measures (PO2). However, the exact assessment depends mainly on the penetration rate assessment in the baseline scenario (and hence the potential of the policy options to increase the uptake).

Hence, the (additional) inspection costs in PO2 are assessed to be higher than the inspection costs in PO1 (also consider Figure 2for an example presenting the effects different policy options have on the uptake of FCW in M1 vehicles). An overview of the inspection costs included in the CBA is presented in Table 13. Inspection costs materialize in both policy options.

**Table 13. Discounted value of maintenance and periodic inspection costs (in millions of €).**

<table>
<thead>
<tr>
<th>Inspection costs</th>
<th>PO1: Voluntary measures</th>
<th>PO2: Mandatory measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCW</td>
<td>€ 4,925</td>
<td>€ 8,481</td>
</tr>
<tr>
<td>LDW</td>
<td>€ 5,114</td>
<td>€ 8,937</td>
</tr>
<tr>
<td>SLI</td>
<td>€ 6,128</td>
<td>€ 14,577</td>
</tr>
<tr>
<td>Bundle (FCW, LDW, SLI)</td>
<td>€ 5,114</td>
<td>€ 8,937</td>
</tr>
<tr>
<td>DDR</td>
<td>€ 5,583</td>
<td>€ 10,974</td>
</tr>
<tr>
<td>REV</td>
<td>€ 5,613</td>
<td>€ 10,282</td>
</tr>
<tr>
<td>TPM</td>
<td>€ 848</td>
<td>€ 2,008</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>€ 173</td>
<td>€ 455</td>
</tr>
<tr>
<td>112 eCall</td>
<td>€ 2,878</td>
<td>€ 3,549</td>
</tr>
</tbody>
</table>

**Repair costs**

In addition to the impact on maintenance costs, retrofit ADAS will affect vehicle repair costs. Material damages to vehicles, infrastructure, freight and personal property resulting from accidents can be assumed to be fully internalized by traffic participants through insurance (van Essen et al., 2019).

Three studies that have considered the impact of ADAS on vehicle repair costs, find that ADAS has opposite effects on the number of repairs and the costs per repair. On the one hand, ADAS are related to an increase in average damage costs. When a vehicle is damaged, the repairs also concern the reparation or replacement of ADAS sensors/cameras, increasing the costs. On the other, ADAS affect the number of damage/crash events in each category, especially reducing more severe crashes.

A study by Thatcham Research and the Association of British Insurers (ABI) finds that average vehicle repair costs have increased by 32% to some € 2,275 in the three years leading up to June 2017 (Thatcham Research, 2017). The study concludes that while ADAS may not account for the entire increase, it is definitely a major contributor.

The application of new techniques, innovative materials and increased prices for parts, drive average costs per repair upwards. ADAS require the installation of a variety of

\(^{18}\) Based on requirements adopted in the Netherland. A vehicle has to undergo ten periodical technical inspection before it reaches 15 years. (*Algemene Periodieke Keuring, APK*).
cameras and sensors. When these sensors are placed ahead of the metallic structure of the vehicle (e.g. bumper), this makes them susceptible to damage in even quite low speed collision. Also windscreen replacement is becoming more expensive, due to the need for recalibration of complex sensors and screen-mounted cameras after repair to make sure these are operating correctly. With vehicles increasingly becoming pieces of software, rather than hardware, the requirement for further diagnostic checks and resets has also increased, to ensure any software is properly recalibrated to original standards. This does not only makes spare parts more expensive, it also requires for additional training and specialist equipment, making repairs more expensive.

At the same time, the study finds that ADAS will reduce the number of damages in longer term and eventually overall damage costs will decrease. Although, the study warns that in the short term, drivers could be lulled into a false sense of security by the marketing of new driver assistance features. Terms used in marketing, such as “full self-driving capability”, give a false impression of a level of autonomy and may trigger drivers’ overreliance on the systems, which could result in crashes and dangerous driving. Such warnings have been echoed by a large number of researchers and stakeholders.

Studies by the GDV (2017) and Bovag (2019) reach similar conclusions on the impact of ADAS on repair costs.

GDV (2017) considers the impact of increased penetration of six ADAS in the passenger car fleet on vehicle insurance compensations, which accounted for 90 percent of damage compensation in 2015 in Germany. Amongst others, the report concludes assistance systems have no influence on many damages and in practice, in real traffic conditions, prevent less damage than assumed in theory.

In vehicle insurance, average repair costs in comprehensive insurance will rise by approximately four to ten percent by 2035. At the same time, compensation for motor vehicle damage decreases by 12 to 24 percent over the same period, as the number of claims (i.e. accidents) will reduce as a result of increased use of ADAS. Overall, compensations will fall by 7 to 15 percent by 2035 compared to 2015 as a result of the new systems.

BOVAG (2019) considers the impacts of increased ADAS penetration in the vehicle fleet on the vehicle repair and maintenance sector in The Netherlands. The study concludes four groups of ADAS have substantial potential to reduce damage. Together they could reduce damages by as much as 30 percent between 2018-2030. Adjusted for rising prices of spare parts and additional need for calibration work, the turnover in the sector could decrease by 11 percent in 2030.

It should be noted that the above studies focus on the impact of factory fitted ADAS and estimate the impact compared to the current situation.

In order to obtain an estimate of the impact of promoting voluntary retrofit of ADAS (PO1) compared to the reference scenario, the same approach as GDV (2017) has been adopted. The impact is the result of the relevance (i.e. type of accidents that can be prevented), efficiency (i.e. the extent damage from these accidents can be prevented), utilisation (i.e. activation) and penetration rate of the ADAS in the vehicle fleet. Assuming there are no major differences between factory and retrofit ADAS in relevance, efficiency and utilisation, the impact on insurance claims of an increased penetration rate ADAS due to retrofitting can be estimated. The following table shows the results.
Table 14. Impact of retrofit ADAS on insurance claims compared to the reference scenario

<table>
<thead>
<tr>
<th></th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>PO 1 Third-party liability</td>
<td>-2%</td>
<td>-3%</td>
<td>-1%</td>
</tr>
<tr>
<td>PO 1 Optional hull damage</td>
<td>-1%</td>
<td>-1%</td>
<td>0%</td>
</tr>
<tr>
<td>PO 1 Overall</td>
<td>-2%</td>
<td>-2%</td>
<td>-1%</td>
</tr>
<tr>
<td>PO 2 Third-party liability</td>
<td>-8%</td>
<td>-3%</td>
<td>-1%</td>
</tr>
<tr>
<td>PO 2 Optional hull damage</td>
<td>-5%</td>
<td>-2%</td>
<td>0%</td>
</tr>
<tr>
<td>PO 2 Overall</td>
<td>-6%</td>
<td>-3%</td>
<td>-1%</td>
</tr>
</tbody>
</table>

The results in the Table 14 should be considered as a very rough estimate of the impact of retrofit ADAS on repair costs. Calculations are based on various assumptions, for each of which there is a level of uncertainty. This uncertainty is also mentioned as key reason for insurance companies in the United States not to offer insurance discounts for vehicles fitted with ADAS. Reuters (Bellon, 2019) reported US insurers are not prepared to offer discounts for vehicles fitted with ADAS due to a lack of data to back up claims by auto manufacturers of reduced risk. The insurance companies cite car manufacturers’ reluctance to provide detailed information on models sold with those features, a lack of consistent standards, drivers’ unpredictable use of the systems and higher repair costs.

Furthermore, total insurance statistics do not provide a complete picture of the total vehicle damage. Information about the completeness of insurance statistics is required to be able to estimate total vehicle damage. For example, a review of vehicle damage costs in three countries in Wijnen & Stipdonk (2016) show damage not included in insurance statistics makes up about 20% to 50% of total vehicle damage. At the same time, it is noted that third-party liability insurance claims relate to costs for material damages as well as bodily harm. The share of the latter in the total third-party liability costs differs significantly between Member States, ranging from 60 percent in Spain, France and Italy to below 15 percent in Estonia, Czech Republic and Sweden (Insurance Europe, 2019).

Given the considerations above, we conclude that the number of repairs is expected to decrease, but the average reparation costs are likely to increase. Although there is some evidence pointing towards a decrease in the insurance claims, implying a decrease in repair costs, the decrease is limited and surrounded by a reasonable level of uncertainty. To be on the conservative side, it is not assumed that measures stimulating retrofitting of vehicles affect repair costs. Hence, the effect on repair costs is estimated to be zero.

Concluding remarks

In the cost-benefit analysis, maintenance costs are expected to be negligible and are assumed to be (close to) 0.

To ensure that the safety benefit (Section 6.3) is justified, inspection costs (to ensure a proper functioning of the retrofit ADAS) are taken into account in both policy options. We assume that each retrofitted vehicle has an additional costs for period technical inspection, à € 15 – 25.

An effect on damage costs is not taken into account. ADAS are expected to decrease the number of claims, but increasing the average amount per claim. There is some evidence pointing at an overall decrease in damages. However, this assessment is fairly uncertain and the decrease was estimated to be limited. To be on the conservative side, it assumed that the overall effect is (close to) 0.

Overall, only inspection costs are taken into account in the CBA. Damage and maintenance costs are assumed to be unaffected by the policy options.
6.2.3 Campaign costs
In accordance with the effectiveness of campaigns, the cost of campaigns are taken into account. In recent years, several campaigns have focused on improving the road safety. They either function as way to discourage drink driving, less cellphone usage or a more general road safety message. Examples of these campaigns and the respective costs are presented in Annex C, but include:

- Czech Republic: Think or you’ll pay!
- Ireland: Various road safety campaigns
- Australia: Optimal expenditures
- Netherlands: BoB-campaign Winter 2016
- United Kingdom: THINK Drink Drive Campaign

To be able to include the costs of a similar road safety campaign in our CBA assessment, a two-step approach has been adopted.

First, an analysis is made of the costs of a variety of road safety campaigns. Within most cases the costs for these campaigns range from 1.5 to 2.5 million euro per year. The length of these campaigns differs wide from three weeks to several years. In the assessment, it is assumed that the campaign lasts for 1 year, and costs between € 1.5 to € 2.5 million per year per Member State.

Furthermore, it is assumed that in policy option 1 (voluntary measures) every European Member State wants to create awareness on retrofitting ADAS by running a road safety. The total campaign costs are extrapolated to a European wide scale by multiplying the average European annual cost of campaign per member state (as determined in step 1) with 28. This lead to an estimate for the campaign costs of € 42 million (low) and € 70 million (high)

Concluding, the discounted campaign costs in the low and high scenario are respectively € 40 million and € 67 million. These values are also presented in Table 15.

Campaign costs only materialize in policy option 1.

<table>
<thead>
<tr>
<th>Table 15. Discounted value of campaign costs (in millions of €)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost component</strong></td>
</tr>
<tr>
<td>Campaign costs</td>
</tr>
</tbody>
</table>

6.2.4 Subsidy costs
As demonstrated by examples in Flanders and Germany, subsidy schemes can be used to promote the further uptake of retrofit ADAS.

Besides the expected benefits of similar schemes in Flanders and Germany, are also costs associated with such schemes, which need to be included in the CBA analysis. In order to optimize the effectiveness of such a subsidy scheme, the scheme is assumed to run for three consecutive years (launch of the campaign in 2026).

Considering practical example 4 (i.e. Flanders subsidies), the total subsidy costs per retrofitted truck equal € 1,550. The total subsidy costs per retrofitted truck are extrapolated the a European level based on the additional uptake of such a measure. The annual budget of subsidies equals € 9 to 11 billion (dependent on the year) and the discounted value of subsidy costs that are needed to run a European wide subsidy scheme for 3 years equals roughly € 28 billion. These costs can be seen as redistribution effects; the subsidy provided is a price reduction for the purchaser. Hence, the societal costs equal 0.
However, the (administrative) costs of setting up and running a subsidy scheme should be taken into account in the CBA. Based on an analysis of administrative and management costs of subsidy schemes in the Netherlands it is found administrative and management costs of subsidy schemes range from 3 to 10 percent of the total amount of the subsidies provided. These ratios are also applied in the CBA. In our lower estimate on costs, the subsidy costs are estimated to be 3%, in our higher estimate on costs, the subsidy costs are estimated to be 10%. The discounted value of the subsidy costs are presented in Table 16.

The subsidy costs only materialize in policy option 1.

Table 16. Discounted value of subsidy costs (in millions of €).

<table>
<thead>
<tr>
<th>Cost component</th>
<th>Share of setting up a subsidy scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low (3%)</td>
</tr>
<tr>
<td></td>
<td>High (10%)</td>
</tr>
<tr>
<td>Subsidy costs</td>
<td>€ 850</td>
</tr>
<tr>
<td></td>
<td>€ 2,800</td>
</tr>
</tbody>
</table>

6.2.5 Other non-quantifiable costs

A number effects of retrofitting ADAS are not quantifiable within the scope of this study or have a negligible effect. These effects are qualitatively included in the CBA analysis.

- Public acceptance
- Standardisation
- Certification

The abovementioned effects are described in the next sections.

6.2.5.1 Public acceptance

Stakeholders expect the public acceptance of mandatory measures for retrofitting ADAS to be very limited. As the value of the (lack of) public acceptance is not quantifiable, these costs are not taken into account in the CBA. However, it has to be noted that these non-monetary costs are expected when considering policy option 2.

6.2.5.2 Standardisation

Since standardisation (as well as certification) is already in place or under development for mandatory factory-fitted ADAS in EU by UN/ECE, there is no need for additional development of standardization. Only minor adjustments needed e.g. for UN/ECE or Euro NCAP test protocols.

As already discussed in section 3.2.1, the retrofitting of ADAS is mainly restricted by the access to in-vehicle data. In general, the retrofitted ADAS could benefit and could provide more integrated system and HMI if a standardised access to in-vehicle data and resources would be available.

However, for the retrofit ADAS, selected to this study, retrofit ADAS providers have found solutions to read the required real-time vehicle data. With this limited data access to vehicles, they have been able to develop similar functionality as factory-fitted ADAS. Therefore, additional standardisation work for in-vehicle data access for third-parties can be recommended but it is not urgently needed for selected set of retrofit ADAS.

Most of the retrofit ADAS, selected to this study, are stand-alone systems, which do not have any external interfaces. Only the Speed Limit Information system may benefit from

---

external (map and speed limit) information. Nevertheless, retrofit ADAS can utilise the same information sources from external service or information providers as the factory-fitted systems. Therefore, there is no need for additional standardisation work related to external information sources of retrofit ADAS.

The additional costs for standardisation have therefore not been considered for the estimation of costs.

6.2.5.3 Certification

In both policy options (voluntary and mandatory measures), criteria for the performance of retrofit ADAS and certification must be set up. The general view in the stakeholder consultation was that the retrofit ADAS should be tested against e.g. UN/ECE requirements and with similar type-approval tests. For factory-fitted ADAS, UN/ECE regulations already exist for several functionalities, and new regulations are under preparation or should be coming up. These regulations can also be used for retrofit ADAS. Only a few UN/ECE existing regulations should be adapted for downgraded warning type retrofit ADAS. The status of the current regulations for retrofit ADAS:

- **FCW**: For M2,N2,M3 and N3, UN/ECE regulation 131 can be used for vehicle detection (UN/ECE, 2016b). For M1 and N1 vehicles, UN/ECE regulation 152 on AEB UN/ECE comes into force in January 2020, and addresses both car and pedestrian detection (UN/ECE, 2019a). Test scenarios for cyclists are still under work in UN/ECE (UN/ECE, 2019d), but are included in the Euro NCAP protocols for AEB (Euro NCAP, 2018a). The current UN/ECE regulations do not define a clear threshold Time-To-Collision (TTC) for FCW warning. TTC thresholds for FCW for vehicles are defined in e.g. the National Highway Traffic Safety Administration (NHTSA) FCW test procedures (NHTSA, 2013).
- **LDW**: UN/ECE LDW regulation 130 for M2,N2,M3 and N3 vehicles can be used for retrofit LDW testing (UN/ECE, 2016a).
- **TPM**: UN/ECE regulation 141 (for M1 and N1 vehicles) (UN/ECE, 2016c)
- **VIS-DET**: UN/ECE regulation 151 (UN/ECE, 2019c)
- **REV**: UN/ECE regulation under development (UN/ECE, 2019b)
- **SLI** and **DDR**: not yet available.
- **112 eCall**: standardisation and certification procedures for retrofit eCall to be defined by the sAFE project (sAFE, 2019).

The certification of retrofit ADAS could follow the certification of the new vehicle safety measures. The needed adaptations for UN/ECE regulations seems to be very small, the costs of these are insignificant.

6.3 **Benefits of ADAS retrofitting**

In this study, only the safety benefit of retrofitting ADAS is considered. This approach is similar to the approach adopted in SWD/2018/190. In reality, retrofitting ADAS could also offer other benefits. For example, the installation of REV might reduce material damage resulting from incorrectly parking a vehicle. Also, the prevention of road accidents is likely to reduce congestion resulting from them and hence increase the fluency of traffic (reducing greenhouse gas emissions and fuel costs). These additional benefits are not taken into account in the CBA.

The safety benefit is expressed as the potential of the ADAS to reduce road fatalities and injury accidents. This reduction in casualties is monetized by using the Value of a Statistical Life (VOSL). The unit value is deduced from SWD/2018/190.

It has to be noted that the unit value, used in SWD/2018/190 and adopted in this study, differs from the unit value described in the Handbook External Costs of Transport (ECOT) (van Essen et al., of 2019). This Handbook is used to assess and monetize the external
effects of policy measures relating to transport in Europe. In a sensitivity analysis, CBA results in which the unit values described in the ECOT handbook are used, are presented.

6.3.1 Description of safety benefits (direct and indirect)

The direct and indirect safety effects of ADAS were identified based on the ADAS descriptions defined in the early stages of this project and based on findings from earlier studies.

The direct safety effects of each ADAS are described in Table 17. These direct effects are estimated to occur immediately after the implementation of the safety measure (in this case the use of retrofitted ADAS).

**Table 17. Direct safety effects by ADAS.**

<table>
<thead>
<tr>
<th>ADAS</th>
<th>Direct safety effects</th>
</tr>
</thead>
</table>
| DDR  | - Accident reduction for cases in which drowsiness, prolonged inattention or distraction are among the main contributory factors (Seidl et al., 2017)  
- False and omitted alarms are probable, likely reducing the potential safety benefits of the system (Wilmink et al., 2017) |
| FCW  | - Prevention of rear-end-collisions between vehicles and collisions between vehicle front and pedestrians and/or cyclists caused by driver inattention (Bax. et al., 2016) |
| SLI  | - Improved awareness of speed limits and offences will reduce unintentional speeding (Wilmink et al., 2008). Reduced impact speed will decrease accident severity (Wilmink et al., 2008; Seidl et al., 2017) |
| LDW  | - Reduction of highway and rural road accidents in which the car would run off the road or face oncoming traffic, as well as highway accidents where roadside object collisions are likely (see e.g. Utriainen, 2019; Sternlund, 2017; Jermakian, 2011) Accident consequences may be reduced if correctional swerve already in progress (Wilmink et al., 2008) |
| REV  | - Accident reduction and reduced severity following improved driver view of or detection of persons or obstacles behind reversing vehicles (Seidl et al., 2017)  
- Safety benefits especially for the elderly and young children, who are identified as especially vulnerable to reversing accidents (Seidl et al., 2017) |
| TPM  | - TPM can alert of underinflated tires, which can help maintain vehicle stability (van Zyl et al., 2013)  
- Underinflated tires may result in increased stopping distance (Seidl et al. 2017) |
| VIS-DET | - Road accident reduction due to detection of pedestrians and cyclists in or nearby path of vehicle (European Commission, 2016) |
Table 18: Direct safety effects

<table>
<thead>
<tr>
<th>ADAS</th>
<th>Direct safety effects</th>
</tr>
</thead>
</table>
| 112 eCall | - Number of road fatalities can be reduced due to shorter emergency service response time (Wilmink et al., 2008)  
- Some part of road fatalities would shift to severe injuries, and some of severe injuries would shift to slight injuries (Abele et al., 2004). Accident severity reduction is especially significant for cases where time delay between accident and emergency call is unusually long, or accident has been located incorrectly (Wilmink et al. 2008).  
- eCall can assist emergency services to reach accidents that are unlikely to be noticed in rural environments, during off-peak hours and/or at low traffic volumes (Wilmink et al. 2008)  
- Shorter emergency response time and better location information improves efficiency of road operator’s incident management – reduced follow-on accidents occurring as a result of the original accident (Wilmink et al. 2008) |

The indirect safety effects of each ADAS are described in Table 18. The indirect effects refer to the long-term changes in road user behaviour which involve learning processes and experiences leading to behavioural adaptation. These indirect effects also cover the changes in exposure of road users and/or changes in the behaviour of non-users.
### Table 18. Indirect safety effects by ADAS.

<table>
<thead>
<tr>
<th>ADAS</th>
<th>Indirect safety effects</th>
</tr>
</thead>
</table>
| DDR  | • Users may trust the system to compensate for their lack of driving ability during drowsiness. This safety net effect may enable drivers to drive longer despite drowsiness (Seidl et al., 2017)  
• System availability may reduce overall alertness of driver, especially under conditions favourable to drowsiness (e.g. extended driving time during hours of darkness) (Wilmink et al., 2008)  
• Increased risk-taking from driver reliance on systems, as well as the transferring of responsibility for fatigue recognition (Jackson et al., 2011)  
• Modal shift from other transport modes to DDR-equipped vehicles expected (Wilmink et al., 2008) |
| FCW  | • Drivers may place trust in system warnings and drive faster than they ordinarily would (Bax et al., 2016) |
| SLI  | • Conformance of speeds may occur in the long-term, as slower drivers are known to increase their speed as a result of system use (Wilmink et al., 2008)  
• Vehicles surrounding ISA-vehicle may be influenced by traffic calming effect (Seidl et al., 2017)  
• Perceived safety of active travel may increase, encouraging its increased prevalence as a car alternative, improving public health (Seidl et al., 2017) |
| LDW  | • Driver alertness may be reduced if trust is partially shifted to system (Wilmink et al., 2008) |
| REV  | • System may act as an enabling technology for drivers, especially the elderly, who may suffer from restricted head/neck motion range (Seidl et al., 2017) |
| TPM  | • No indirect effects were identified |
| VIS-DET | • Improved visibility may reduce driver’s perceived workload in urban environments (Seidl et al., 2017)  
• Overreliance on system by drivers can lead to negative safety effects (Bax et al., 2016)  
• System could increase perceived safety for VRUs, particularly concerning HGVs and busses, potentially encouraging modal shift to active travel as a car and public transport alternative in urban environments (Bax et al., 2016; Seidl et al., 2017) |
| 112 eCall | • Travel time savings may be incurred from reduced emergency response time (Wilmink et al. 2008) |

#### 6.3.2 Estimates on effectiveness based on earlier studies

##### 6.3.2.1 Drowsiness and distraction recognition (DDR)

Ecorys (2006) estimated based on literature review and stakeholder consultations that fatigue detectors could prevent 10% (range 5–15%) of fatalities and serious injuries.

Wilmink et al. (2008) estimated that driver drowsiness monitoring and warning could potentially prevent 1.5–7.0% of fatal road accidents and 1.0–4.9% of road injuries in EU-25 in full penetration rate.
Seidl et al. (2017) highlighted in their study that there is no high-quality evidence of the effectiveness of driver warning systems from retrospective studies. Some stakeholders in their study commented that no evidence of existing systems’ benefits in real world conditions was available.

6.3.2.2 Forward collision warning (FCW)

A study conducted by Highway Loss Data Institute (HLDI, 2017) investigated the effects of crash avoidance features by comparing rates of police-reported crashes and insurance claims for vehicles with and without the technologies. Regarding forward collision warning the study found that it could reduce front-to-rear-crashes by 27% and front-to-rear-crashes with injuries by 20%.

Cicchino (2016) estimated that forward collision warning could reduce rear-end striking crash involvements by 23%. The reductions of rear-end striking crashes with injuries and with third party injuries were not statistically significant (6% and 4% respectively). If looking at all crashes, forward collision warning reduced the accident involvement in all crashes by 12%, multi-vehicle crashes by 11%, injury crashes by 15% and third party injury crashes by 6%. From these, reductions related to all crashes, multi-vehicle and injury crashes were significant. This estimate is similar to the findings of Leslie et al. (2019) who assessed—based on safety system content of over 3.7 million vehicles provided by General Motors and by police-reported data from vehicles involved in crashes— that camera-based Forward Collision Alert (FCA) is estimated to reduce rear-end striking crashes by 21%.

According to Lubbe & Kullgren (2015) the effectiveness of forward collision warning in casualty cost reduction ranged from “no benefit” for an audio-visual warning system with late activation, to a benefit of 25% casualty cost reduction for an early activating warning system including an additional short brake pulse.

Wilmink et al. (2008) estimated that emergency braking could potentially prevent 3.1–8.8% of fatal road accidents and 3–8.9% of road injuries in EU-25 in full penetration rate.

6.3.2.3 Speed limit information (SLI)

A speed limit information system does not intervene in the driving task; it only informs the driver of speed limits and of speeding. Therefore, safety is mainly influenced by improved awareness of the actual speed limit and of speeding offences (Wilmink et al. 2008).

Wilmink et al. (2008) estimated that speed alert (informs about speed limit and speeding) could potentially prevent 4.5–12.6% of fatal road accidents and 2.6–9.5% of road injuries in EU-25 in full penetration rate.

The iMobility effects database (2017) has collected information on in-vehicle speed limit systems that provide information on locally valid speed limit to the driver. This information can be displayed continuously, or via targeted warnings near road signs, or if the driver exceeds or drives slower than the locally valid speed limit. The database summarises that in-vehicle speed limits are estimated to reduce road fatalities and injuries by 2–7% (iMobility effects database, 2017).

Based on the data collected from ISA field trials in the UK, Lai et al (2012) and Carsten et al. (2008) estimated that advisory ISA could avoid 2.7% and voluntary ISA 12.0% of all injury accidents on roads in the UK with 100% fleet penetration. The corresponding number for mandatory ISA was 28.9%. These field trials used a fleet of 20 identical vehicles which were driven by 79 drivers. The results showed that advisory ISA is
estimated to be substantially less effective than the intervening (voluntary and mandatory) form of ISA.

The European Commission (2014) commissioned a study in which the effects of mandatory speed limitation device directed to Heavy Duty Vehicles (HDVs) (including N2, N3, M2 & M3 vehicles) were evaluated. The analysis based on relationships between the speed distributions and accident rates showed that Speed Limitation Directive had a positive impact on road safety. The use of speed limiters in HCVs was estimated to result in reduction of 9% of fatal accidents on motorways with HCVs involved, 4% of serious injuries and 3% of injury accidents. The reduction percentages for Heavy Goods Vehicles (HGVs) (N2 & N3 vehicles) were estimated to be similar as for all HCVs. However, the estimates for buses (M2 & M3 vehicles) resulted in reduction of 13% of fatal accidents, 7% of seriously injured and overall a reduction of 4% for all injury accidents on motorways with buses involved.

6.3.2.4 Lane departure warning (LDW)

Utriainen (2019) conducted an in-depth analysis of Finnish fatal road accidents between 2014–2016. Utriainen found out that Lane Keeping Assist (LKA) could prevent 27% of fatal single vehicle accidents and head on collisions. LKA could prevent 19% of all fatal road accidents if the system would be used in all vehicles. The study of Utriainen (2019) assumed that LKA does not work in poor weather conditions or in case the lane markings are poor. In addition, it excluded fatal road accidents which were estimated to be caused intentionally, or which occurred due to sudden medical problems such as heart attacks.

Wilmink et al. (2008) estimated that lane keeping support could potentially prevent 5.7–21.8% of fatal road accidents and 3.9–13.6% of road injuries in EU-25 in full penetration rate.

Sternlund (2017) discovered in a Swedish in-depth study of fatal car crashes in 2010 involving lane departure that LDW could potentially prevent 33–38 of 100 head-on and single-vehicle crashes. The studied accidents occurred on roads with visible lane markings and without rumble strips on the lane departure side of the road. 81% of lane departure crashes studied were considered to involve drifting, which could have been avoided by LDW. As the drifting crashes seemed to rarely involve loss of control, the drivers were considered available to respond to warnings.

The above results are supported by a study of single-vehicle and head-on crashes in the USA based on data from 2004–2008. Jermakian (2011) found that LDW could potentially mitigate or prevent 31% of fatal and 10% of non-fatal injury single-vehicle crashes annually, as well as 46% of fatal and 35% of nonfatal injury head-on crashes annually. In general, LDW was found to potentially prevent or mitigate up to 179,000 crashes per year, which corresponds to 3% of all crashes studied, and prevent almost one in four fatal accidents involving passenger vehicles. Jermakian (2011) only included crashes that were deemed relevant for the LDW to affect them in the analysis. For example, this involved excluding crashes such as running off road due to an avoidance manoeuvre for single-vehicle crashes, and crashes involving more than two vehicles or crashes involving a vehicle defect for head-on accidents.

Cicchino (2018) observed effects of LDW on single-vehicle, sideswipe and head-on crashes based on data from 25 US states during 2009–2015. In the study, observed crashes for vehicles with LDW were compared with expected crash counts based on crash involvement rates for passenger vehicles without LDW. For relevant crashes involving injuries of all severities, the effect of LDW was estimated with Poisson regression models. When controlling for demographic variables in the analysis, the results indicated that LDW could reduce accidents by 11% for crashes of all severities, as well as by 21% for crashes with injuries. Accidents involving fatalities were too few to include in the analysis. Cicchino (2018) mentions crucially that LDW systems are
often such that the user must switch them on. In light of this, it was considered puzzling that LDW performed so well for accident prevention while previous studies such as Reagan, et. al. (2018) and Flannagan, et. al. (2016) have shown that use rates of LDW hover around 50% for vehicles with the option in US studies.

A study conducted by Highway Loss Data Institute (HLDI, 2017) investigated the effects of crash avoidance features by comparing rates of police-reported crashes and insurance claims for vehicles with and without the technologies. The study found out that lane departure warning could reduce single-vehicle, sideswipe and head-on crashes by 11% and injury crashes of the same type by 21%.

Leslie et al. (2019) estimated the effectiveness of Lane Departure Warning by analysing the safety system content of over 3.7 million vehicles provided by General Motors and by combining this information with the police-reported data from vehicles involved in crashes. They found out that LDW could prevent 10% of lane departure crashes. However, it was noted in this study that the relative low usage of LDW systems (can be easily switched off) may be an important limiting factor in obtaining higher effectiveness estimates.

6.3.2.5 Reversing detection system (REV)

Keall et al. (2017) estimated based on road accident data from New Zealand and four Australian States that reversing cameras could prevent 41% of targeted vehicle-pedestrian accidents with camera based systems and 31% with a system equipped with sensors only.

According to National Highway Traffic Safety Administration (2014) rear visibility systems are predicted to have an effectiveness of 28–33% which is substantially higher than for sensor-only systems. As a target population, this study used light vehicle reversing crashes involving non-occupants of vehicles such as pedestrians and cyclists.

It must be noted that the majority of back over injuries to pedestrians are probably not within the scope of most official road injury recording systems, which just focus on public roads and thus excluding car parks, private driveways, company yards, etc. Hence, there is a large potential for underestimating the target population of reversing cameras when using official accident statistics or in-depth data such as GIDAS or RAIDS. (Keall et al. 2017, Seidl et al. 2017).

6.3.2.6 Tyre pressure monitoring (TPM)

The use of TPM can prevent under-inflated tyres and therefore have a safety benefit due to maintaining vehicle stability (van Zyl et al. 2013).

Reithmaier & Salzinger (2003) estimated that 3.3% of all tyre related accidents could be related to tyre pressure. The total percentage of tyre-related accidents in all reported motor vehicle accidents with personal injury in Germany has remained nearly constant at 0.4%. By combining official German road accident statistics with in-depth data Reithmaier & Salzinger (2003) concluded that 0.34–2.5% of all accidents were tyre-related accidents.

van Zyl et al. (2013) estimated that properly maintaining the tyre inflation pressure can reduce the number of speed and tyre related accidents by 4% to 20%, and the total number of Light Commercial Vehicle (LCV) and Heavy Duty Vehicle (HDV) accidents by 0.8% up to 4%. However, according to Seidl at al. (2017) several stakeholders have questioned the real-world validity of safety benefit estimation produced by van Zyl et al. (2013) via simulations and modelling. The main concerns is that the values presented by van Zyl et al (2013) are overestimates.
As indicated by van Zyl et al. (2013) having implemented TPM does not necessarily mean that tyre under-inflation is completely prevented. Based on earlier studies van Zyl et al. (2013) stated that mandatory fitment of TPM does not guarantee that 100% of tyres will be correctly inflated. Jansen et al. (2016) also highlighted that the user is required to take action in case of warning of low tyre pressure, and in that respect consumer awareness is very relevant. It is also important that the air filling stations provide correct pressure indication not to confuse the drivers. (Jansen et al. 2016).

6.3.2.7 Vulnerable road user detection and warning (VIS-DET)

Bax et al. (2016) studied the impact of VIS-DET in the VRUITS study, and estimated that blind spot detection could result in 0.4–0.8% decrease in all road fatalities and 0.7–1.3% decrease in road injuries in the EU-28 assuming that all passenger cars and heavy vehicles are equipped with the system (Bax et al. 2016, Silla et al. 2014). This study assumed that for pedestrians, the number of blind spot accidents (and thus also the impact of the system) is negligible since their behavior and position on the road differ from that of a cyclist.

Stakeholders in Seidl et al. (2017) study estimated that effectiveness of direct vision in preventing the target accidents for pedestrian collisions is likely less than 66%, and for cyclists less than 50%.

6.3.2.8 112 eCall

The 112 eCall aims to reduce the emergency response time for road accidents and thus to mitigate the consequences of road accidents.

iMobility effects database (2017) summarises based on several studies that eCall is estimated to reduce road fatalities in Europe by 3.6–7.3% in EU-25 in full penetration rate. It also states that some fatalities will shift to serious injuries. The review showed that some estimates on the impacts on serious injuries are contradictory. Wilmink et al. (2008) originally reported the estimate provided in iMobility effects database.

Francsics et al. (2009) estimated on the basis of 14 studies that eCall could reduce road fatalities by 1–6% and serious injuries by 0.5–2% in Europe depending on the country cluster. This estimate was done as part of a larger study aiming to summarise the results of previous national and regional studies for the impact assessment of eCall on a European scale. These impacts covered safety, efficiency, environmental and economical impacts as well as other implementations issues such as ethical, environmental, financial and legal issues. Francsics et al. (2009) also found that impact of reduced rescue time varies by country due to geography and performance of emergency services.

According to a Finnish study (Virtanen et al. 2006), eCall could reduce 4–8% of road fatalities and 5–10% of motor vehicle occupant deaths in Finland. Virtanen et al. (2006) also stated that due to Finland having high number of lightly trafficked roads and severe winter conditions, the self-alarming eCall system could be more beneficial in Finland than in the rest of Europe.

6.3.3 Estimation of safety potential

The safety effects were quantified based on the estimates of the safety effects from earlier studies. In general, these studies estimate the safety potential based on factory-fitted systems with a well-functioning and switched-on ADAS.

*The safety effects were estimated for a hypothetical situation in which there is no vehicle on the road fitted with ADAS, hence assuming a 0% penetration rate. Therefore, the found effects require some ‘scaling’ to account for the*
situation in which the penetration rate is not 0%. More attention to this scaling is provided in the section 6.3.4.

It is the view of stakeholders that retrofit ADAS in principle are able to offer the same safety potential as the factory-fit ADAS. Furthermore, it is assumed that ADAS are well-functioning\textsuperscript{20}, and that the systems are always switched-on.

In reality, it is possible that road users decide to switch off their system. For example, the Dutch Safety Board (2019) recently concluded that vehicle drivers are not able to handle ADAS, and are therefore likely to switch them off. It is expected that ADAS familiarity will increase autonomously (for example as a result of the Regulation (EU) 2019/2144, and hence the usage rates of ADAS will increase. In order to account for the current situation, in which road users might switch off ADAS, we test the CBA results by performing a sensitivity analysis by assuming that only 75% of the retrofit ADAS installed in vehicles will yield safety benefits.

The summary of the estimates for the accident reduction by ADAS based on earlier studies are presented in Table 19. In cases where no range was provided for the estimate, our calculations assumed that there is ±20\% variation in the estimate.

<table>
<thead>
<tr>
<th>ADAS</th>
<th>Estimate on accident reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDR</td>
<td>All road fatalities by 1.5–7.0% and road injuries by 1.0–4.9% in EU-25 (Wilmink et al., 2008)</td>
</tr>
<tr>
<td>FCW</td>
<td>FCW: Rear-end striking crash involvements by 23% (Cicchino, 2016)</td>
</tr>
<tr>
<td></td>
<td>FCW-PCD (pedestrians): 12.2% for fatalities and 10.5–21.1% for injuries (applied from Seidl et al., 2017)</td>
</tr>
<tr>
<td></td>
<td>FCW-PCD (cyclists): 13.8% for fatalities and 8.2–16.4% for injuries (applied from Seidl et al., 2017)</td>
</tr>
<tr>
<td>SLI</td>
<td>Speed Alert: All road fatalities by 4.5–12.6% and road injuries by 2.6–9.5% in EU-25 (Wilmink et al., 2008)</td>
</tr>
<tr>
<td></td>
<td>In-vehicle speed limits: All road fatalities by 2–7% in EU-28 (iMobility effects database, 2017)</td>
</tr>
<tr>
<td>LDW</td>
<td>All road accidents by around 10% in EU-28 (iMobility effects database, 2017)</td>
</tr>
<tr>
<td>REV</td>
<td>Relevant vehicle-pedestrian accidents by 41% with camera based systems (Keall et al., 2017)</td>
</tr>
<tr>
<td>TPM</td>
<td>Total number of N1, N2, N3, M2 &amp; M3 accidents by 0.8% up to 4% (Zyl et al., 2013)</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>All road fatalities by 0.4–0.8% and road injuries by 0.7–1.3% in EU-28 (Bax et al., 2016)</td>
</tr>
<tr>
<td>112 eCall</td>
<td>All road fatalities by 3.6–7.3% and road injuries by 0.0% in EU (Wilmink et al., 2008; iMobility effects database, 2017)</td>
</tr>
</tbody>
</table>

The assumptions used in the effectiveness calculations are presented in Table 20. This table is followed by Table 21 that presents estimated safety benefits by ADAS and by bundle (FCW, FCW-PCD, SLI, LDW). It is important to be noted that the benefits

---

\textsuperscript{20} This assessment is justified by also taking into account costs for inspection and (potential) recalibration, see section 6.2.2.
presented in Table 21 are calculated with 100% penetration rate, compared to situation with no ADAS (neither factory-fitted nor retrofitted).

Table 20. Assumptions used in calculations.

<table>
<thead>
<tr>
<th>ADAS</th>
<th>Assumptions used in calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCW-VEH</td>
<td>Share of rear-end collisions was estimated based on CARE database (6.9% of fatalities and 15.4% of injury accidents). Share of M1 &amp; N1 vehicles in rear-end collisions were estimated based on Finnish (2011–2015) and Swedish (2009–2013) road accident data (Peltola &amp; Luoma, 2017; Peltola &amp; Luoma, 2016). According to these statistics M1 and N1 vehicles are involved in 65–73% of fatal rear-end collisions and in 89–92% of rear-end collisions resulting in injuries.</td>
</tr>
<tr>
<td>FCW-PCD</td>
<td>The effectiveness estimates for FCW-PCD were derived from Seidl et al. (2017). They estimated that AEB-PCD (for pedestrians) could prevent 24.4% relevant fatalities and 21.0–42.1% of relevant injuries. The corresponding numbers for AEB-PCD (for cyclists) were 27.5% for fatalities and 16.4–32.8% for injuries. However, based on previous studies (Leslie et al., 2019; Cicchino 2016) it was assumed in our calculations that the effectiveness of FCW is approximately half of the effectiveness of AEB. The total number of pedestrian and cyclist fatalities were taken from the statistical pocketbook. The share of pedestrian accidents and multi vehicle accidents involving cycles from all injury accidents were estimated based on analysis of CARE database conducted by Bax et al. (2016). According to the accident data in 2012, these shares were 13.4% and 10.5%. Rosén (2013) estimated based on German GIDAS database from 1999–2012 that 85% of pedestrians and 85% of cyclists killed in road accidents were struck by the vehicle front. The corresponding shares for injury accidents were 76% and 77%.</td>
</tr>
<tr>
<td>LDW</td>
<td>Reduction estimates indicated in previous table were applied to the total number of road fatalities (25,651) and injury accidents (1,009,075) reported to the statistical pocketbook (European Commission, 2018d). The same reduction estimates were applied to all vehicle categories since no better estimate was available.</td>
</tr>
<tr>
<td>SLI</td>
<td>Reduction estimates indicated in previous table were applied to the total number of road fatalities (25,651) and injury accidents (1,009,075) reported to the statistical pocketbook (European Commission, 2018d). Based on Seidl et al. (2017) we assumed that to half the effectiveness of SLI for N2, N3, M2, M3 vehicles is half of that for M1&amp;N1 vehicles (considered as part of CBA calculations).</td>
</tr>
<tr>
<td>Bundle (FCW, LDW, SLI)</td>
<td>This assessment uses the estimated safety effects for each retrofit ADAS as a starting point. The safety benefits for FCW and LDW were summed together. The targeted accidents for SLI were identified to be partly overlapping with FCW and LDW and hence the combined (summed) effectiveness of FCW and LDW was multiplied by the effectiveness of SLI.</td>
</tr>
<tr>
<td>DDR</td>
<td>Reduction estimates indicated in previous table were applied to the total number of road fatalities (25,651) and injury accidents (1,009,075) reported to the statistical pocketbook (European Commission, 2018d). The effectiveness was estimated to be similar for all vehicle categories (Seidl et al., 2017).</td>
</tr>
</tbody>
</table>
The bundle (FCW, FCW-PCD, SLI and LDW) was estimated to reduce road fatalities by 12.9–27.2% and injury accidents by 8.4–23.4%. Høye et al. (2015) estimated the safety effects of a bundle including ACC with FCW and AEB, pedestrian warning with AEB, LDW, informative ISA and Alcohol interlock. They estimated based on Delphi study with 41 experts that this bundle could reduce 19% of road fatalities and serious injuries with 100% penetration. The bundle considered in this study is somewhat more limited with its functionalities. The lower limit of our estimate is relatively close to the estimate of Høye et al. (2015). However, our upper estimate is relatively high compared to Høye et al. (2015).
6.3.4 Correcting for a penetration rate above zero

The previous section provided the potential of the studied ADAS to decrease the yearly number of road fatalities and injury accidents. The safety potential describes the (maximum) effectiveness of (retro)fitting a fleet with the specific ADAS.

However, part of the fleet is already fitted with ADAS in our baseline scenario. Therefore, the safety potential in Table 19 should be ‘scaled’ to estimate the safety benefit that can actually be obtained.

In our analysis, it is assumed that the penetration rate moves linear with the safety potential. Thus, if the effect a policy option is an increase in the uptake of X%, the safety benefit potential in Table 19 is scaled by taking X% of the maximum potential.

As Section 5.4 highlighted, the effect of the policy options on the penetration rate differs per year. The policy options have a high impact on the penetration rate in early years, as the number of vehicles eligible for retrofitting is highest. As the number of retrofittable vehicles decreases over time, the effects that policy options have on the penetration rate decreases. This implies that the safety benefit (that is, the percentage increase in the penetration rate multiplied by the safety benefit potential) decreases over year as the impact of the policy options on the penetration rate decreases.

The way that the maximum safety potential is scaled to estimate the achieved safety benefit implicitly assumes that the safety benefit moves linearly with the penetration rate. In reality, it is likely that this relationship is non-linear.

ADAS are expected to be more effective when the majority of road users have these installed (as non-equipped vehicle drivers are influenced by the driving behaviour of equipped vehicles). The more vehicles are equipped with ADAS, the higher the safety benefit expected to be. However, the specific nature of the relationship between the penetration rate and the safety effects of ADAS is currently unknown. Hence, the relationship is assumed to be linear as has been assumed in SWD/2018/190.

6.3.5 Number of prevented casualties

The number of prevented casualties (as a result of retrofitting) over the period 2026–2041 is presented as a percentage reduction relative to the baseline assessment over this period. The overview is presented in Table 22.

The reader has to keep in mind that all ADAS are scored individually to avoid issues concerning double counting. However, this implies that the reader cannot simply ‘add’ the percentages to find the overall number of prevented casualties as a result of a policy option, as this leads to double-counting (as one fatality could be prevented by multiple ADAS).
Study on the feasibility, costs and benefits of retrofitting ADAS to improve road safety

### Table 22. Prevented fatalities over the evaluation period 2026–2041.

<table>
<thead>
<tr>
<th>Retrofit ADAS</th>
<th>PO1: Voluntary measures</th>
<th>PO2: Mandatory measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>FCW</td>
<td>0.7%</td>
<td>1.1%</td>
</tr>
<tr>
<td>LDW</td>
<td>0.7%</td>
<td>1.1%</td>
</tr>
<tr>
<td>SLI</td>
<td>0.2%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Bundle</td>
<td>1.2%</td>
<td>2.6%</td>
</tr>
<tr>
<td>DDR</td>
<td>0.2%</td>
<td>0.7%</td>
</tr>
<tr>
<td>REV</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>TPM</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>0.0%</td>
<td>0.1%</td>
</tr>
<tr>
<td>112 eCall</td>
<td>0.2%</td>
<td>0.4%</td>
</tr>
</tbody>
</table>

The results of Table 22 show that the bundle has the highest effect on the number of fatalities. However, this does not necessarily mean that it is cost-effective, as the retrofit product is fairly expensive. The cost-benefit analysis in which the costs are compared with the (safety) benefits is presented in Section 6.4.

#### 6.3.6 Assessment of the target population

Besides the scaling of the maximum safety potential with the safety benefit, the safety effect is also made vehicle-specific. The maximum safety potential is, besides the scaling to account for the penetration rate increase, further broken down to estimate the safety benefit per vehicle category. This is done based on the historical number of collisions (to develop an estimate per vehicle category regarding injuries) and the historical number of fatalities (to develop an estimate per vehicle category regarding fatalities) per vehicle category. The historical numbers of collisions and fatalities per vehicle category are taken from SWD/2018/190.

The allocation of the safety potential to the different vehicle categories (distinguishing between injuries and fatalities) is presented in Table 23. For REV and VIS-DET, which are specifically focused on the prevention of collisions involving VRUs, a slightly different target population has been applied. For these ADAS, only injury accidents and fatalities involving VRU are taken into account.

#### Table 23. Share of fatalities and injury accidents by vehicle category among those accidents that involve M1, M2, M3, N1, N2 or N3 vehicles (European Commission, 2018c).

<table>
<thead>
<tr>
<th>Vehicle category</th>
<th>Fatalities</th>
<th>Injury accidents</th>
<th>VIS-DET and REV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fatalities involving VRUs</td>
</tr>
<tr>
<td>M1</td>
<td>84%</td>
<td>85%</td>
<td>75%</td>
</tr>
<tr>
<td>M2&amp;M3</td>
<td>2%</td>
<td>2%</td>
<td>4%</td>
</tr>
<tr>
<td>N1</td>
<td>8%</td>
<td>8%</td>
<td>10%</td>
</tr>
<tr>
<td>N2&amp;N3</td>
<td>6%</td>
<td>5%</td>
<td>11%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

#### 6.3.7 Functioning of the model

Based on the information in Section 6.3 and the effects of the different policy options on the uptake of the penetration rate (summarized in Section 5.4) the model calculates the number of prevented fatalities and injury accidents relative to the baseline assessment (presented in Annex E). The model works as follows:
6.3.8 Monetization of casualties prevented

The prevented casualties (as a result of retrofitting ADAS) are monetized using the unit values from SWD/2018/190, which are provided in Table 24. As has been mentioned in the introduction of Section 6.3, these unit values differ from the unit values presented in the Handbook on the External Costs of Transport (Van Essen et al., 2019).

<table>
<thead>
<tr>
<th>Casualty</th>
<th>Unit value (2019 prices)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>€ 2,100,490</td>
</tr>
<tr>
<td>Injury</td>
<td>€ 63,757</td>
</tr>
</tbody>
</table>

From Table 24, one can deduct that (on average) a prevented fatality is ‘valued’ at €2,100,490 and a prevented injury at €63,757.

6.4 Results

6.4.1 CBA results

The results of the CBA are provided in Table 25. As has been mentioned in Section 6.1, the results are expressed in a benefit-to-cost ratio (BCR). The results are associated with a bandwidth (low and high). The low estimate is depicted on the left side in each cell, followed by a semicolon and the high estimate. Results that have a BCR above 1 in both the low and high estimate are bolded; the benefits in both scenario’s exceed the costs for these ADAS-vehicle combinations.

It is chosen to assess each retrofit ADAS individually. It is not possible to develop the ‘overall’ cost-effectiveness of a policy options, as for this one needs to correct for double-counting (one fatality might be prevented by multiple ADAS). Because this is a tricky exercise, it is decided to assess each retrofit ADAS individually.

A comparison between the methodology adopted by SWD/2018/190 and the methodology adopted in this study is provided in Annex F.
Table 25. CBA results for two different policy options (benefit-to-cost ratio).

<table>
<thead>
<tr>
<th>Retrofit ADAS</th>
<th>PO1: Voluntary measures</th>
<th>PO2: Mandatory measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M1</td>
<td>M2&amp;M3</td>
</tr>
<tr>
<td>FCW</td>
<td>0.3 ; 0.8</td>
<td>0.3 ; 0.6</td>
</tr>
<tr>
<td>LDW</td>
<td>0.7 ; 1.4</td>
<td>0.5 ; 1.1</td>
</tr>
<tr>
<td>SLI</td>
<td>0.2 ; 1.4</td>
<td>0.2 ; 1</td>
</tr>
<tr>
<td>Bundle</td>
<td>0.5 ; 1.6</td>
<td>0.4 ; 1.3</td>
</tr>
<tr>
<td>DDR</td>
<td>0.1 ; 0.6</td>
<td>0.3 ; 2.4</td>
</tr>
<tr>
<td>REV</td>
<td>0 ; 0.1</td>
<td>0.1 ; 0.3</td>
</tr>
<tr>
<td>TPM</td>
<td>0.1 ; 0.9</td>
<td>0 ; 0.2</td>
</tr>
<tr>
<td>VIS-DET</td>
<td><strong>2.2 ; 7.3</strong></td>
<td><strong>0.5 ; 1.6</strong></td>
</tr>
<tr>
<td>112eCall</td>
<td>0.1 ; 0.3</td>
<td>0 ; 0.2</td>
</tr>
</tbody>
</table>

From Table 25, it can be observed that VIS-DET offers a positive BCR (for both the lower as the higher estimate) for M2&M3 vehicles, in both policy options. This implies that retrofitting VIS-DET in M2&M3 vehicles is considered cost-effective (e.g. the safety benefit exceeds the purchase, installation and policy-specific costs).

For trucks and trailers (N2&N3), the BCR is considerably lower than for buses and coaches (M2&M3). Although M2&M3 vehicles are involved in fewer accidents/road fatalities than N2&N3 vehicles (also see Table 23), their fleet size is also considerably smaller (see Table 8). Hence, the safety benefit of retrofitting N2&N3 vehicles is higher, but the costs are also. In detail, the European N2&N3 fleet is roughly eight times higher as the fleet of European M2&M3 vehicles (Table 8), while the number of injury accidents and road fatalities is only 2-3 times higher for trucks compared to buses (Table 23). The net effect is a lower BCR for N2&N3 than for M2&M3 vehicles.

The obtained results for VIS-DET are also in line with current (retrofit) practices throughout Europe: VIS-DET is the most targeted ADAS system in pilots or incentive schemes (described in section 4.4). In practice, these incentive schemes mainly focus on trucks that are active in urban regions. The current incentive schemes therefore provide some indication that measures stimulating retrofitting VIS-DET on N2&N3 vehicles that frequently visit urban areas might be (even more) cost-effective. This is not surprising as the VIS-DET system focuses mainly on pedestrian and cyclists. The majority of accidents involving these (vulnerable) road users occurs in urban areas.

The data to perform such an exercise is lacking. Ideally, one would have information regarding the number of vehicles that drive mainly in urban areas (such as garbage trucks, and city buses), and exclude long-haul trucks that rarely enter urban areas. However, only information regarding the number of vehicle kilometres driven in urban areas is available. An analysis, in which only a share of trucks is retrofitted with VIS-DET, is included in sensitivity analysis 4.

Besides the results for VIS-DET, Table 25 offers some other insights. A somewhat puzzling result is the high BCR for M2&M3 vehicles retrofitted with SLI in case of mandatory measures (PO2). These vehicles have speed limiters installed under Directive 92/6/EEC. This means that they already have some instruments in place that prevent them from speeding on highways and motorways (a speed limiter is typically set at 90km/h – 100km/h). Hence an additional instrument might not yield an additional safety benefit.

---

21 The found safety estimates for vehicles, cyclists and pedestrians are summed. FCW systems address all groups of road users.
However, M2&M3 vehicles are still able to speed on roads with a speed limit that is lower than the maximum speed of the speed limiter. On roads that are not highways, there is a higher amount of accidents (Transport & Mobility Leuven et al., 2013). This means that SLI is able to yield an additional safety benefit on these roads.

Moreover, a study conducted by the Norwegian Institute of Transport Economics (2014) concluded that if all vehicles abide to the speed limit, Intelligent Speed Adaptation (ISA)\(^ {22}\) is considered to be cost-effective in Norway. This evidence supports the high BCR presented in Table 25.

In addition, it can be observed that retrofitting REV has the smallest BCR and is thereby not cost-effective. The CBA only considers the safety benefit, while it could well be that REV is able to prevent material damage from occurring (for example while parking). The prevented damage costs are not taken into account in this analysis.

In general, the BCR for M2&M3 vehicles are highest for each retrofit ADAS. The primary reason for this is that the fleet of M2&M3 vehicles is relatively small, but they are involved in a relatively large number of collisions (see also Table 23 and Table 8).

6.4.2 Development of costs and benefits over time

More insights on how costs and benefits are offered and how they develop during the evaluation period are presented in Figure 3. This provides an overview in which the costs and benefits are presented for each year. The figure is meant to offer an example\(^ {23}\), and presents the costs and benefits (higher estimate, representing low costs and high benefits) of policy option 1 (voluntary measures) for retrofitting FCW on M1 vehicles.

The associated BCR in Table 25 are made italic (both equal to 0.8).

![Figure 3. Example of costs and benefits development for policy option 1, retrofitting FCW in M1 vehicles. The figure represents the ‘high’ BCR of Table 25.](image)

What can be observed from Figure 3 is that purchase and installation costs (and associated administrative costs of the subsidy scheme) occur in the first three years. The campaign costs (in the year 2026) are relatively small.

\(^{22}\) ISA is considered to be a more sophisticated version of Speed Limit Information (SLI).

\(^{23}\) For other ADAS/vehicle combinations, the size of the effects differ. The figure is only offered as an example on how costs and benefit develop over time.
The safety benefit increases in the first three years, and remains constant at around €1 billion up till 2034. As the effect of PO1 on the penetration rate decreases over time, the safety benefit of PO1 also decreases. In 2041, only a very small safety benefit is observed.

From 2028 onwards, inspection costs are taken into account as they (just as the safety benefit) depend on the penetration rate. Their development is comparable with the safety benefit. In practice, the inspection costs are fairly constant in the period 2028–2034 and decrease from 2035 onwards. In 2041, the inspection costs are minimal.

The black-dotted line represents the difference between the safety benefit (blue bar) and the associated costs. In the first three years, the difference between benefits and costs is negative, indicating that costs are higher than benefits. In the period 2029–2041, the benefits exceed the costs. However, the overall discounted value of the costs are higher than discounted value of the safety benefit, which results in a BCR equal to 0.8 (see Table 25).

To give better insights in how costs and benefits develop over time, the same figure is also generated for PO2 (see Figure 4). The picture presents the higher estimate (representing low costs and high benefits) of retrofitting FCW in M1 vehicles.

![Figure 4. Example of costs and benefits development for policy option 2, retrofitting FCW in M1 vehicles. The figure represents the 'high' BCR of Table 25.](image)

What can be observed from Figure 4 is that the purchase and installation costs are higher in PO2 than in PO1. This is because more M1 vehicles are retrofitted with FCW (also consider section 5.4). The safety benefit and the size of the inspection costs are also higher in PO2. However, the safety benefit (and inspection costs) decrease steeper than in Figure 3. These effects remain constant for a period of 6 years in PO1 (Figure 3), the safety benefit and inspection costs in PO2 increase steeply in the first two years and then decrease quite rapidly to arrive at a value close to 0 in 2041. Just as in PO1, the BCR of this specific ADAS/vehicle combination is estimated at 0.9 in the higher estimate (see Table 25).

### 6.5 Sensitivity analysis

In this section, three sensitivity analyses are performed to test the impact of changing a number of key inputs and test the robustness of the CBA results. The assumptions and results for every sensitivity analysis are discussed below.
6.5.1 Sensitivity Analysis 1

In the first sensitivity analysis, the estimated safety benefits are subject to the sensitivity test. Retrofit ADAS are in a theoretical situation able to offer the same safety potential as factory fitted ADAS and retrofit systems are assumed to function well. In practice, there is not much evidence regarding the safety benefit that a retrofit ADAS is able to offer. So, although factory-fitted and retrofitted ADAS are assumed to offer the same safety benefits in this study, this assumption is relaxed in this sensitivity analysis. In this sensitivity analysis, it is assumed that retrofit ADAS is able to offer only 75% of the safety effects presented in section 6.3.

The CBA outcomes that result from using a lower safety effect (i.e. 75% of the safety effect) are presented in Table 26. All other assumptions are in line with the CBA analysis in sections 6.1 to 6.3 (and therefore remain unchanged in this sensitivity analysis).

Table 26. CBA results for sensitivity analysis 1 (benefit-to-cost ratio).

<table>
<thead>
<tr>
<th>Retrofit ADAS</th>
<th>PO1: Voluntary measures</th>
<th>PO2: Mandatory measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M1</td>
<td>M2&amp;M3</td>
</tr>
<tr>
<td>FCW</td>
<td>0.3 ; 0.6</td>
<td>0.4 ; 0.5</td>
</tr>
<tr>
<td>LDW</td>
<td>0.5 ; 1.1</td>
<td>0.4 ; 0.8</td>
</tr>
<tr>
<td>SLI</td>
<td>0.2 ; 1</td>
<td>0.1 ; 0.8</td>
</tr>
<tr>
<td>Bundle</td>
<td>0.4 ; 1.2</td>
<td>0.3 ; 1</td>
</tr>
<tr>
<td>DDR</td>
<td>0.1 ; 0.4</td>
<td>0.1 ; 0.8</td>
</tr>
<tr>
<td>REV</td>
<td>0 ; 0.1</td>
<td>0.2 ; 0.3</td>
</tr>
<tr>
<td>TPM</td>
<td>0.1 ; 0.7</td>
<td>0 ; 0.3</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>1.6 ; 5.4</td>
<td>0.3 ; 1.2</td>
</tr>
<tr>
<td>112eCall</td>
<td>0 ; 0.2</td>
<td>0 ; 0.2</td>
</tr>
</tbody>
</table>

Overall, the benefit-to-cost ratios are lower in Table 26 than in Table 25. This can be explained, because the safety effect is estimated to be smaller. While taking into account these lower safety effects (and thereby lower benefits), VIS-DET still has a positive BCR (for both the lower and higher estimate as well as both policy options). Retrofitting VIS-DET for M2&M3 vehicles can still be considered cost-effective. This does not hold for retrofitting SLI for M2&M3 vehicles in case of a mandatory policy option (PO2). Mandatory retrofitting of SLI for M2&M3 vehicles is not considered cost-effective in the lower estimate when taking into account a lower safety effect.

6.5.2 Sensitivity Analysis 2

In the second sensitivity analysis, the results are brought in line with the European guidelines. This means that the prescriptions laid down in the Better Regulation Guidelines and the Handbook on the External Costs of Transport are adopted.

In practice, the following two inputs of the CBA are changed:

- The discount rate. The Better Regulation Guidelines (Toolbox #61) prescribes that a discount rate of 4% should be used, while SWD/2018/190 adopts a discount rate of 4.25%. To ensure that the main results (Table 25) are in line with SWD/2018/190, the results in Table 25 are calculated using a discount rate of 4.25%.
- The monetisation of prevented casualties. The Handbook on the External Costs of Transport (2019) prescribes a value of € 3,392,782 per prevented fatality, while SWD/2018/190 adopts a value of € 2,102,569. To ensure that the main results (Table 25) are in line with SWD/2018/190, the results in Table 25 are calculated using a monetisation of 2,102,569.
Thus, the inputs used to compose the CBA are not entirely in line with European Guidelines. In order to bring the results in line with European Guidelines, the discount rate has been set at 4% instead of 4.25% and the monetisation of prevented casualties is set at € 3,392,782 for fatalities and € 120,781 for injuries (instead of € 2,102,569 and € 63,757 respectively).

The CBA outcomes that results from assuming a different discount rate and a modified VOSL are presented in Table 27. All other assumptions and inputs are left unchanged.

### Table 27. CBA results for sensitivity analysis 2 (benefit-to-cost ratio).

<table>
<thead>
<tr>
<th>Retrofit ADAS</th>
<th>PO1: Voluntary measures</th>
<th>PO2: Mandatory measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M1</td>
<td>M2&amp;M3</td>
</tr>
<tr>
<td>FCW</td>
<td>0.6 ; 1.5</td>
<td>0.5 ; 1.1</td>
</tr>
<tr>
<td>LDW</td>
<td>1.2 ; 2.6</td>
<td>0.5 ; 3.4</td>
</tr>
<tr>
<td>SLI</td>
<td>0.4 ; 2.5</td>
<td>0.7 ; 2.3</td>
</tr>
<tr>
<td>Bundle</td>
<td>0.9 ; 2.8</td>
<td>0.5 ; 3.4</td>
</tr>
<tr>
<td>DDR</td>
<td>0.2 ; 1.1</td>
<td>0.6 ; 3.4</td>
</tr>
<tr>
<td>REV</td>
<td>0.1 ; 0.1</td>
<td>0.2 ; 0.5</td>
</tr>
<tr>
<td>TPM</td>
<td>0.2 ; 1.7</td>
<td>0.3 ; 1.7</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>4.1 ; 13.6</td>
<td>0.8 ; 3.4</td>
</tr>
<tr>
<td>112eCall</td>
<td>0.1 ; 0.3</td>
<td>0.1 ; 0.3</td>
</tr>
</tbody>
</table>

The results in Table 27 show that the BCR are considerably higher than in Table 25. Retrofitting LDW, SLI, DDR, VIS-DET and the bundle appear to be cost-effective for various vehicle types and in different policy options. Retrofitting DDR in M2&M3 vehicles is considered cost-effective in PO2. In addition, retrofitting LDW in M1 & N1 vehicles is considered to be cost-effective for both policy options. Lastly, retrofitting VIS-DET in N2&N3 vehicles is considered cost-effective in this sensitivity analysis, for both policy options.

#### 6.5.3 Sensitivity Analysis 3

The third sensitivity analysis concerns a different cost assessment. The CBA results shown in section 6.4, assume that the costs of retrofitting ADAS are similar to the costs of factory fitted ADAS in SWD/2018/190, including a mark-up to account for aftermarket installation costs. This third sensitivity analysis uses the purchase costs of retrofit systems that are currently available on the market. These market based purchase costs are retrieved from market analysis and are presented in Table 7. The installation costs remain unchanged.

The CBA results that assume market based purchase costs of retrofitting devices are presented in Table 28. All other assumptions and inputs are left unchanged.
Table 28. CBA results for sensitivity analysis 3 (benefit-to-cost ratio).

<table>
<thead>
<tr>
<th>Retrofit ADAS</th>
<th>PO1: Voluntary measures</th>
<th>PO2: Mandatory measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M1</td>
<td>M2&amp;M3</td>
</tr>
<tr>
<td>FCW</td>
<td>0.1 ; 0.8</td>
<td>0.1 ; 0.6</td>
</tr>
<tr>
<td>LDW</td>
<td>0.1 ; 1.4</td>
<td>0.1 ; 1.1</td>
</tr>
<tr>
<td>SLI</td>
<td>0.1 ; 1.5</td>
<td>0.3 ; 2.6</td>
</tr>
<tr>
<td><strong>Bundle</strong></td>
<td>0.3 ; 1</td>
<td>0.2 ; 0.8</td>
</tr>
<tr>
<td>DDR</td>
<td>0 ; 0.6</td>
<td>0.2 ; 2.3</td>
</tr>
<tr>
<td>REV</td>
<td>0 ; 0.1</td>
<td>0.1 ; 0.3</td>
</tr>
<tr>
<td>TPM</td>
<td>0.1 ; 0.9</td>
<td>0 ; 0.2</td>
</tr>
<tr>
<td>VIS-DET</td>
<td><strong>1.1 ; 5.3</strong></td>
<td>0.2 ; 1</td>
</tr>
<tr>
<td>112eCall</td>
<td>0.1 ; 0.3</td>
<td>0 ; 0.2</td>
</tr>
</tbody>
</table>

Table 28 shows that the bandwidth of the CBA results have increased, which has considerable consequences on the outcomes. There is only ADAS/vehicle combinations that has a positive BCR when assuming market based purchase costs. This is largely due to the fact that current prices observed on the market have a substantial cost range.

6.5.4 Sensitivity Analysis 4

In this sensitivity analysis, an assumption regarding the share of N2&N3 vehicles that visit urban areas is adopted. To rate the cost-effectiveness of VIS-DET, which is aimed at improving the safety of cyclists and pedestrians, a detailed assessment regarding the retrofittable fleet might result in a ‘fairer’ comparison. For example, long-haul trucks rarely visit urban areas, and therefore the safety benefit of retrofitting a long-haul truck is expected to be negligible, whereas the safety benefit retrofitting a garbage truck might be substantial (since this vehicle category is expected to drive in urban areas more often). For buses, this refinement is less necessary since buses (especially those active in urban transport) drive mostly in urban areas.

Unfortunately, information on the number of the number of N2&N3 vehicles driving in urban areas is lacking. There is some information available on vehicle kilometres driven in urban areas. ERTRAC (2019) finds that around 80% of transportation (in terms of tonnekilometres) of N2&N3 vehicles can be considered long haul. The UK Department of Transport (2017) found that around 28% of all vehicle kilometres driven by N2&N3 vehicles takes place on urban areas. In this sensitivity analysis, it is assumed that by retrofitting 25% of all N2&N3 vehicles, one can reap the full safety benefits. One has to keep in mind that this is a gross estimate, since the sources concern vehicle kilometres and not vehicle fleet size.

The results are presented in Table 29.
If only 25% of all N2&N3 vehicles are retrofitted with VIS-DET, the measure is considered to be cost-effective. This suggests that measures stimulating the retrofitting of N2&N3 vehicles in urban areas might be considered cost-effective. However, to make a detailed assessment, better information is needed regarding the fleet size of N2&N3 vehicles that drive the majority of kilometres on urban roads (such as garbage trucks or supply trucks for retail activities).
7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The main objective of this study was to investigate the inventory of available retrofit ADAS on the market and provide a clear assessment of the technical feasibility of these retrofitting products (chapter 3). In addition, current penetration rates of ADAS in the EU vehicle fleet and their expected development over time are assessed, as well as already existing measures that stimulate the uptake (chapter 4). Based on existing measures and their assessed effectiveness, policy measures and their expected effects have been developed (chapter 5). Measures stimulating the uptake of retrofitting ADAS come with costs and benefits. These expected impacts of retrofitting ADAS are captured for two different policy options and tested in a cost-benefit analysis (chapter 6). This final chapter summarizes the main findings of the study.

7.1.1 Technical feasibility

- Retrofit ADAS has limited real-time access to in-vehicle data, but cannot get access to actuators such as brakes. This is unlikely to change in the near future.
- For all of the ADAS included in Regulation (EU) 2019/2144, retrofit ADAS are available on the market. There are already a number of retrofit ADAS freely available on the market that provide multiple functionalities (e.g. camera-based FCW, LDW, SLI, etc).
- For optimal performance, professional installation is recommended.

7.1.2 Baseline scenario

- The penetration rate of ADAS is expected to increase due to the Regulation (EU) 2019/2144, that will make several ADAS mandatory for new vehicles. The potential impact that retrofitting has on the penetration rate decreases over time. Some EU Member States have implemented a couple of initiatives to increase the penetration of (retrofit) ADAS in the EU vehicle fleet.
- Despite these developments, it is not expected that the autonomous growth of retrofit ADAS will be substantial. The number of vehicles equipped with retrofit ADAS is expected to remain small in a scenario without additional EU intervention.

7.1.3 Stimulating measures to retrofit ADAS

- In this study, two types of policy options have been identified:
  - 1) measures that stimulate the penetration rate of ADAS via retrofitting on a voluntary basis.
  - 2) measures that mandate vehicle owners to retrofit their vehicle.
- A voluntary policy option concerns an awareness raising campaign and a subsidy scheme. This results in an expected increasing uptake of 3.0 and 3.7 percentage points.
- In the case of mandatory retrofitting, consulted stakeholder expect the public acceptance to be very low. This holds especially for measures mandating retrofitting passenger cars and less for trucks, busses and coaches.
- In the analysis, vehicles are exempted from the analysis when it is considered to be not economically feasible. That is, when the residual value exceeds the costs of a retrofit ADAS. In the light of this economic perspective, passenger cars and light commercial vehicles from 15 years are excluded from our analysis.

7.1.4 Costs benefit analysis

- The costs included in the CBA are: purchase and installation costs, subsidy costs, campaign costs and inspection costs. Damage, maintenance, standardization and
certification costs are assumed to be negligible and hence not taken into account in the CBA. The benefits of retrofitting ADAS are a monetization of prevented casualties as a result of retrofit ADAS.

- The CBA results shows that VIS-DET offers a positive benefit-to-costs ratio for both policy options and is thereby cost-effective for M2&M3 vehicles in both policy options. Retrofitting SLI is considered cost-effective for M2&M3 vehicles in the policy option mandating retrofitting.
- By looking at the different types of vehicles, retrofitting buses and coaches (M2&M3 vehicles) receive the highest BCR. The main reason for this is that the fleet is relatively small compared to the other vehicle classes (hence costs are rather low) and this vehicle category is involved in a relatively large number of collisions (hence the potential for a reduction in casualties is rather high).

7.1.5 Sensitivity analysis

- Three sensitivity analyses have been performed to test the robustness of the CBA results:
  - using a different safety effect (sensitivity analysis 1);
  - using a different valuation of casualties prevented together with a changed discount rate (sensitivity analysis 2);
  - using a different assessment of purchase costs for retrofit ADAS (sensitivity analysis 3)
- The CBA results are fairly robust for sensitivity analyses 1 and 2, but not for sensitivity analysis 3.

7.2 Recommendations

- Standardisation: Retrofit systems would benefit from a standardised access to in-vehicle data, such as indicator signals. CAN data can be read without physical access, e.g. through CAN-bus sniffers. Retrofit manufacturers have found solutions to get access to the data in these vehicles. It would be beneficial if vehicle manufacturers open this data, so that they are open to all retrofit device manufacturers.
- The bundle FCW+LDW+SLI has substantial safety potential. In case the whole vehicle fleet is retrofitted with the retrofit bundle the number of fatalities could be reduced by 1.2–2.6% for the voluntary measures options and by 2.4–5.2% for the mandatory measures during the evaluation period. The costs for the bundle are high, resulting in BCR below 1. Price development for this ADAS should be closely monitored as the safety potential is highest.
- According to the CBA, retrofitting buses and coaches with VIS-DET could come into consideration for voluntary and mandatory measures. For public transport vehicles, the fitment of buses with VIS-DET could be a requirement in the procurement. In addition, a more targeted approach for retrofitting VIS-DET in N2&N3 vehicles in urban regions could have positive effect on the cost-effectiveness of the measure for N2&N3 vehicles.
- According to the CBA, also Speed Limit Information for buses and coaches provides good results. Hence, fitment of buses with SLI could be a requirement in the procurement.
REFERENCES


Dutch Safety Board (2019). Who is in control? Road safety and automation in road traffic


European Commission. 2018b Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users, amending Regulation (EU) 2018/... and repealing Regulations


Eurostat. 2018. Transport statistics at regional level

Eurostat. 2019. Wages and labour costs


Israeli Tax Authority, Taxing and selected data for automotive vehicles in Israel 2016, December 2017, full and complete translation of the 5th chapter: Safety Devices in Passenger and Commercial Vehicles


Norwegian Institute for Transport Economics. 2014. Driver support systems: Estimating road safety effects at varying levels of implementation.


Stojanová, H., Blašková, V., Cost benefit study of a safety campaign’s impact on road safety, Accident Analysis & Prevention, vol. 117, pp. 205-2015


van Kalmthout, R. 2017. BoB-campagne winter 2016 (R50) Eindrapportage campagne-effectonderzoek, Kantar Public


## ANNEX A: PENETRATION RATES

Table 30 offers an overview of recent assessments of the penetration rates of ADAS.

### Table 30. Assessment of the penetration rates of ADAS

<table>
<thead>
<tr>
<th>ADAS</th>
<th>Penetration rate</th>
<th>Year</th>
<th>Source</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCW-VEH</td>
<td>4.4–18%&lt;sup&gt;24&lt;/sup&gt;</td>
<td>2012–2015</td>
<td>See footnote 24</td>
<td>New reg. M1</td>
</tr>
<tr>
<td></td>
<td>Negligible</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>N1 fleet</td>
</tr>
<tr>
<td></td>
<td>&gt;50% in 2026</td>
<td>2015</td>
<td>Mandatory (Table 3)</td>
<td>New reg. M2&amp;M3</td>
</tr>
<tr>
<td></td>
<td>&gt;50% in 2026</td>
<td>2015</td>
<td>Mandatory (Table 3)</td>
<td>New reg. N2&amp;N3</td>
</tr>
<tr>
<td>FCW-PCD</td>
<td>Negligible</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>M1 fleet</td>
</tr>
<tr>
<td></td>
<td>Negligible</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>N1 fleet</td>
</tr>
<tr>
<td>LDW</td>
<td>3–31%&lt;sup&gt;25&lt;/sup&gt;</td>
<td>2012–2017</td>
<td>See footnote 25</td>
<td>M1 fleet</td>
</tr>
<tr>
<td></td>
<td>Lower than M1</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>N1 fleet</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>2015</td>
<td>Mandatory (Table 3)</td>
<td>New reg. M2&amp;M3</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>2015</td>
<td>Mandatory (Table 3)</td>
<td>New reg. N2&amp;N3</td>
</tr>
<tr>
<td>Adv. ISA</td>
<td>1–10%</td>
<td>2012</td>
<td>Öörni (2014)</td>
<td>M1 fleet</td>
</tr>
<tr>
<td></td>
<td>1–10%</td>
<td>2012</td>
<td>Öörni (2014)</td>
<td>N1 fleet</td>
</tr>
<tr>
<td></td>
<td>Negligible</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>M2&amp;M3 fleet</td>
</tr>
<tr>
<td></td>
<td>Negligible</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>N2&amp;N3 fleet</td>
</tr>
<tr>
<td>DDR-ADR</td>
<td>17%</td>
<td>2018</td>
<td>Mobile.de website</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; &amp; 2&lt;sup&gt;nd&lt;/sup&gt; hand sales of N2&amp;N3</td>
</tr>
<tr>
<td></td>
<td>Negligible</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>N1 fleet</td>
</tr>
<tr>
<td></td>
<td>Negligible</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>M2&amp;M3 fleet</td>
</tr>
<tr>
<td></td>
<td>Negligible</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>N2&amp;N3 fleet</td>
</tr>
<tr>
<td></td>
<td>Lower than M1</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>N1 fleet</td>
</tr>
<tr>
<td></td>
<td>Similar to</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>M2&amp;M3 fleet</td>
</tr>
<tr>
<td></td>
<td>N2&amp;N3</td>
<td></td>
<td></td>
<td>N2&amp;N3 fleet</td>
</tr>
<tr>
<td></td>
<td>17%</td>
<td>2018</td>
<td>Mobile.de website</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; &amp; 2&lt;sup&gt;nd&lt;/sup&gt; hand sales of N2&amp;N3</td>
</tr>
<tr>
<td>TPM</td>
<td>&gt;50% in 2025</td>
<td>2014</td>
<td>Mandatory (Table 3)</td>
<td>New reg. M1</td>
</tr>
<tr>
<td></td>
<td>Negligible</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>N1 fleet</td>
</tr>
<tr>
<td></td>
<td>Similar to</td>
<td></td>
<td>Assessment not contested in WS</td>
<td>M2&amp;M3 fleet</td>
</tr>
<tr>
<td></td>
<td>N2&amp;N3</td>
<td></td>
<td></td>
<td>N2&amp;N3 fleet</td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td>2015</td>
<td>Rodriguez et al. (2017)</td>
<td>N2&amp;N3 fleet</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>Negligible</td>
<td></td>
<td>Seidl et al. (2017), not contested in WS</td>
<td>M2&amp;M3 fleet</td>
</tr>
<tr>
<td></td>
<td>Negligible</td>
<td></td>
<td>Seidl et al. (2017), not contested in WS</td>
<td>N2&amp;N3 fleet</td>
</tr>
<tr>
<td>112 eCall</td>
<td>&gt;50% in 2029</td>
<td>2018</td>
<td>Mandatory (Table 3)</td>
<td>New reg. M1</td>
</tr>
<tr>
<td></td>
<td>&gt;50% in 2029</td>
<td>2018</td>
<td>Mandatory (Table 3)</td>
<td>New reg. N1</td>
</tr>
</tbody>
</table>


<sup>26</sup> 24% for US fleet in 2016, according to HLDI (2017). 12% refers to autonomous parking assist, which uses reversing camera.
ANNEX B: PURCHASE AND INSTALLATION COSTS OF RETROFIT ADAS

Table 31. Purchases cost estimation for retrofit ADAS (based upon European Commission, 2018c) and approximation of installation time and costs for retrofitting ADAS

<table>
<thead>
<tr>
<th>ADAS</th>
<th>Purchase costs (range)</th>
<th>Installation time/costs</th>
<th>Remark on installation costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower estimate</td>
<td>Higher estimate</td>
<td></td>
</tr>
<tr>
<td>FCW</td>
<td>€ 36</td>
<td>€ 66</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>LDW</td>
<td>€ 57</td>
<td>€ 86</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>SLI</td>
<td>€ 94</td>
<td>€ 126</td>
<td>0.5 hours</td>
</tr>
<tr>
<td>Bundle: FCW, LDW and ISA</td>
<td>€ 186</td>
<td>€ 278</td>
<td>2 hours</td>
</tr>
<tr>
<td>DDR-ADR</td>
<td>€ 150</td>
<td>€ 229</td>
<td>0.5 hours</td>
</tr>
<tr>
<td>REV</td>
<td>€ 25</td>
<td>€ 56</td>
<td>€ 130</td>
</tr>
<tr>
<td>TPM</td>
<td>€ 57</td>
<td>€ 204</td>
<td>€ 150</td>
</tr>
<tr>
<td>VIS-DET</td>
<td>€ 153</td>
<td>€ 509</td>
<td>3.75 hours</td>
</tr>
<tr>
<td>eCall</td>
<td>€ 82</td>
<td>€ 275</td>
<td>0.5 hours</td>
</tr>
</tbody>
</table>

1. Expert judgement
3. Expert judgement
## ANNEX C: ROAD SAFETY CAMPAIGNS

### Table 32  Road safety campaigns

<table>
<thead>
<tr>
<th>Country</th>
<th>Road safety campaign</th>
<th>Total campaign costs</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Czech Rep. (15y)</td>
<td>Think or you’ll pay!</td>
<td>€ 6,000,000</td>
<td>Stojanová &amp; Blašková (2018)</td>
</tr>
<tr>
<td>Ireland (1y)</td>
<td>Various road safety campaigns</td>
<td>€ 625,000</td>
<td>Fitzgerald (2017)</td>
</tr>
<tr>
<td>Netherlands (1y)</td>
<td>Various campaigns</td>
<td>€ 632,000</td>
<td>Rijksoverheid (2018)</td>
</tr>
<tr>
<td>Australia (1y)</td>
<td>'Optimal expenditures'</td>
<td>€ 4,800,000</td>
<td>Australasian Transport Research Forum (2016)</td>
</tr>
<tr>
<td>Netherlands (3w)</td>
<td>BoB-campaign Winter 2016</td>
<td>€ 240,000</td>
<td>van Kalmthout (2017)</td>
</tr>
<tr>
<td>UK (1y)</td>
<td>THINK Drink Drive Campaign</td>
<td>€ 5,000,000</td>
<td>Department for Transport (2014)</td>
</tr>
</tbody>
</table>
ANNEX D: BASELINE ASSESSMENT OF ROAD CASUALTIES

The baseline development of the number of road injuries and casualties is based on the impact assessment SWD/2018/190 (European Commission, 2018c). The authors present the (annual) number of road injuries and casualties in their baseline. Moreover, for each policy option, they describe the annual decrease in road injuries and road casualties. Based on this information, their baseline assessment of road injuries and road fatalities is updated to account for the effects of the updated GSR, Regulation (EU) 2019/2144.

Furthermore, a review is made to find any other (EU) intervention has been announced since SWD/2018/190 has been published, since these might also impact the number of road fatalities and road injuries. An impact assessment affecting road safety (European Commission, 2018e) has been published after SWD/2018/190. The information offered in the road safety related impact assessment did not offer enough information to correct the baseline for the assessed impacts in this document.

Therefore, it has to be noted that the number of injuries and fatalities provided in Table 33 are expected to be somewhat overestimated (the number of injuries and fatalities are expected to be lower than the numbers presented in the table).

This means that the CBA results are likely to be biased upward. However, the bias is expected to be small, indicating that the results of the CBA are still valid.

The baseline assessment of road casualties is presented in Table 33. These numbers have been used to assess the safety benefit originating from an increased uptake of ADAS.

Table 33: Baseline development of road casualties.

<table>
<thead>
<tr>
<th>Year</th>
<th>Injury</th>
<th>Fatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2026</td>
<td>1,367,368</td>
<td>23,185</td>
</tr>
<tr>
<td>2027</td>
<td>1,352,847</td>
<td>22,743</td>
</tr>
<tr>
<td>2028</td>
<td>1,338,197</td>
<td>22,303</td>
</tr>
<tr>
<td>2029</td>
<td>1,323,846</td>
<td>21,874</td>
</tr>
<tr>
<td>2030</td>
<td>1,310,522</td>
<td>21,453</td>
</tr>
<tr>
<td>2031</td>
<td>1,298,414</td>
<td>21,059</td>
</tr>
<tr>
<td>2032</td>
<td>1,287,140</td>
<td>20,698</td>
</tr>
<tr>
<td>2033</td>
<td>1,276,853</td>
<td>20,364</td>
</tr>
<tr>
<td>2034</td>
<td>1,267,498</td>
<td>20,058</td>
</tr>
<tr>
<td>2035</td>
<td>1,258,970</td>
<td>19,779</td>
</tr>
<tr>
<td>2036</td>
<td>1,251,218</td>
<td>19,523</td>
</tr>
<tr>
<td>2037</td>
<td>1,243,997</td>
<td>19,287</td>
</tr>
<tr>
<td>2038</td>
<td>1,237,640</td>
<td>19,121</td>
</tr>
<tr>
<td>2039</td>
<td>1,231,284</td>
<td>18,955</td>
</tr>
<tr>
<td>2040</td>
<td>1,224,927</td>
<td>18,790</td>
</tr>
<tr>
<td>2041</td>
<td>1,218,570</td>
<td>18,624</td>
</tr>
</tbody>
</table>
ANNEX E: ASSESSMENT OF CURRENT RETROFIT ADAS IN THE EU VEHICLE FLEET

While there are various reports that estimate the penetration rate of factory-fitted ADAS in the vehicle fleet in Europe, no sources have been found that assess the uptake of retrofit ADAS in the European fleet.

By combining the information from various ADAS market reports, the current penetration of retrofit ADAS in the total EU vehicle fleet is assessed:

1. A study in the US led by the Specialty Equipment Market Association SEMA (Imlay, 2017) estimates the ADAS technologies aftermarket sales in 2018 in the United States at USD 1.2 billion. With a vehicle fleet of nearly 273 million vehicles and an estimated expenditure on aftermarket sales and retrofit ADAS of some 1,100 USD per vehicle, the penetration of retrofit ADAS in the fleet is 0.4 percent.

2. Market reports on the ADAS sales in the United States estimate the market between USD 3-4 billion.

3. Koggersbøl et al. (2018) estimate the market for retrofit solutions, including ADAS and features on demand systems, in the EU at 3 billion euro in 2017. With a vehicle fleet of nearly 300 million vehicles and an estimated expenditure on retrofit ADAS of some 1,000 euro per vehicle, the penetration of retrofit ADAS in the fleet could roughly be estimated at 1.0 percent.

It is noted that aftersales markets assessed in the mentioned reports include more services and ADAS systems than covered in this report. In particular the latter is considered a high estimate of the retrofit market taking into account assessments of the size of the overall European ADAS market provided in other market reports.

4. Market reports by MarketWatch and SBD estimate the overall European ADAS market at respectively 3.6 billion euro and 2.7 billion euro in 2018.

Applying a similar ratio between the ADAS and retrofit market in Europe as in the United States, and again assuming an average expenditure on retrofit ADAS of some 1,000 euro per vehicle, the penetration of retrofit ADAS in the fleet can be roughly estimated at 0.2-0.4 percent.
ANNEX F. COMPARISON BETWEEN ASSESSMENT METHODOLOGIES

This section compares the methodology for the safety impact and the CBA, used in this report, with the method used in SWD/2018/190 (European Commission, 2018c).

Data

In general, the data sources used are identical for the two studies. Both studies adopt the CARE database as a starting point. However, SWD/2018/190 also considered different accident categories based on UK in-depth road accident data (Stats19). So, they developed queries identifying the nature of collisions (e.g. which vehicles were involved, what factors contributed to the accident). Based on their report, it was not possible to reproduce the resulting assessment, without developing queries based on Stats19 data.

Baseline: methodology

The methodology to construct the baseline is similar in both studies. However, the baseline in this study is corrected for the results of SWD/2018/190. Therefore, the penetration rate of ADAS in this study grows faster and the development of road casualties is different.

Costs: Methodology

The methodology on the cost assessment is equal. However, this study also considers aftermarket installation costs and inspection costs.

Safety: Methodology

The methodology adopted is fairly similar. Both studies estimate the yearly effectiveness of ADAS by scaling the safety potential with the penetration rate. However, SWD/2018/190 applies the safety benefit to a specific target population, retrieved from Stats19 data. In our safety assessment, the safety benefit is applied to the whole population. The safety potential in SWD/2018/190 exceeds the safety potential in our study. Because their safety potential is applied to a smaller population as has been done in our study, the resulting effects on the number of fatalities and injury accidents are comparable. The comparability between the assessments are further secured as both studies use the same sources from literature.

Safety: Severity types considered

SWD/2018/190 considers fatalities, severe and slight injuries. This study considers fatalities and injury accidents (as in the EU Statistical Pocketbook). The safety benefit (in €) that is attributed to prevented fatalities and injuries is equal.

Cost-benefit analysis: methodology

The methodology adopted in this study differs somewhat from the methodology adopted in SWD/2018/190. In this study, it is chosen to ‘rate’ each ADAS-vehicle combination separately. The consequence of this approach is that the overall effectiveness of a policy option cannot be determined. Simply adding up all individual assessments for each ADAS-vehicle combination would result in double-counting of prevented fatalities, as one fatality might be prevented by multiple ADAS. An accident in which a person is distracted, speeding and changing lanes without signaling could for example be prevented by DDR, SLI and LDW.
The methodology adopted by SWD/2018/190 allows for an assessment of the policy option, as they correct for double counting. However, from their report it is not entirely clear how this correction is estimated and applied.

**Cost-benefit analysis: parameters**

The parameters in both studies are equal. Hence, the evaluation period and discount rate are equal. Both studies express the CBA results in a BCR.
ANNEX G: SUMMARY OF THE STAKEHOLDER CONSULTATION

During the study, stakeholders were consulted during several phases. In the first phase, stakeholders (OEMs, device manufacturers, importers, European and national transport safety agencies, insurers and vehicle user associations) were interviewed via phone or physically on the technical feasibility, costs and benefits of retrofitting ADAS. At a workshop held on 11.6.2019, feedback was collected from stakeholder representatives regarding the technical feasibility, safety impact and cost-benefit assessment methodology, cost estimates and safety benefits. The organisations which provided feedback to this study are listed in the report in Table 2. This annex lists the summary of the feedback received from the stakeholders during the study. Listed comments are from a single stakeholder unless otherwise marked.

Technical feasibility

Feedback from the interviews

- There were no substantial stakeholder objections regarding the selection of retrofit ADAS to the study. Some comments were stated:
  - Retrofit ADAS technology must be on level which ensures a sufficient level of safety and fulfills customer expectations. Systems should show benefits to consumer reliably.
  - Only systems which truly provide safety benefits should be promoted, and retrofit ADAS (promoted or not) should not reduce traffic safety or consumers trust towards vehicle safety systems in general.
  - Also Headway Warning (HDM) could be added in addition to FCW, with HDM also FCW would have better impact (as no emergency braking is not available in retrofit). In addition, HDW has positive effect on fuel consumption, due to avoidance of harsh braking.
  - Selection of retrofit ADAS should be based on safety benefit potential and easy to retrofit, it also should be cost efficient, in order to get volumes up. For example, a device with single front looking camera can handle many of these systems.
  - It is important that e.g. camera-based systems are installed professionally, which can provide quality assurance. But some of the systems you cannot install by yourself (e.g. TPM)
  - Retrofit solutions can be as effective as OEM/embedded solutions
  - REV: Proper installation of the reverse camera is important, reverse camera should provide full view of the back of the car.
  - Retrofitted ADAS cannot be compared to not existing factory fitted one. Retrofitted may also have better performance.
  - Standards for retrofitted systems should not be less than OEMs
  - Retrofit ADAS should adhere as a baseline to similar type approval tests as factory-fitted ADAS. However, where such standards (e.g. from UNECE or NHTSA) do not exist these should be defined/ adapted to non-actuated features.
  - If the user may gain incentives or mandatory measures are in place, retrofit ADAS should be tested against e.g. UN/ECE or Euro NCAP requirements and tests.
  - For retrofit LDW (and FCW and other systems) a study could be made as a next step to evaluate effect of these systems. Camera based (FCW) performance can work, but this should be verified with tests. Radar is expensive and maybe not feasible for old cars.
  - Quality of camera-based retrofit devices has increased significantly over the past few years.
  - For DDR there is a need for UNECE regulation. Maybe also retrofit DDR should wait for factory fitted DDR systems to come on the market with tested and verified systems.
Retrofit DDR systems will provide the same functionality as factory fitted when OEM solutions are ready.

Retrofit DDR: optimal position of the camera may be difficult. In heavy vehicles the cabin is so wide and the driver looks a lot in the side mirrors, therefore several cameras are needed for DDR.

FOR VIS-DET (similar to REV) there should not be any invisible areas and driver should rely on what the system shows. Professional installation is needed.

Several functions (e.g. FCW, LDW, ISA) based on camera could be provided with one system, with one installation, this combination could reduce insurance.

If only alerts are provided, the quality does not need to be so high and cheaper mobile phone solutions could be used. But how much these will really provide safety benefits?

Providers are making significant improvements to develop camera with larger field of view. This is particularly imports for scenarios with crossing Bicycles and Pedestrian (e.g. in Euro NCAP). With low cost camera sensors (including mobile phones), field of view may be limited.

**Feedback from the workshop**

- There was no substantial stakeholder objections regarding selection of retrofit ADAS to the study. Some comments were stated:
  - Extracting information from EDR will be technically feasible, but the distinction between technically and politically feasible is important.
  - Headway Monitoring should be included together with Forward Collision Warning as it greatly improves the effectiveness.
  - Today’s vehicles already have all kind of beeps. This leads to distraction and might be even more dangerous. Both positive and negative systems and effects should be considered. In addition, the standardization of the HMI is also an issue.
  - The psychological aspect is an important factor. Mostly active intervention ISA is a suitable way of driving.
  - The system should be on every time the engine restarts. This is a very important factor also for retrofit.
  - The European Commission needs to consider whether these systems are also checked at technical inspections. In addition, concerns in the aftermarket on the calibration was raised. Consider these aftermarket issues, best-practice and technical inspections.
  - The location of the camera is important and especially accessible view area is essential. When installed professionally, the device has no influence on the view area of the vehicle.
  - It is important to define retrofit ADAS compared to what is regulated in Geneva. Technical regulations are well-defined, but as different functionalities are considered this might be different to the definitions in Geneva. The user might be interested in a functionality, but the (technical) rules should then be very clear.
  - Mobile apps are not a viable option for retrofitting ADAS: people do not use their mobile phones for safety mobile applications and using mobile phones should not be allowed in cars.
  - No stakeholder objections to the statement: “If incentives (or mandatory measures) are used the retrofit ADAS need to pass similar tests as type-approval ADAS. This will require professional installation of the retrofit ADAS in order to meet the performance criteria and system to be always on.”

**Costs**

Feedback from the interviews

- The costs of factory fitted ADAS are decreasing over time and are being solid as a standard feature instead only being offered on premium cars.
• Calibration of camera’s is still difficult (especially in retrofit scenario’s).
• The largest part of accident costs are indirect costs of a car accident (for instance personal losses)

Feedback from the workshop

• Today’s market prices of aftermarket ADAS will decrease over time as the market expands.
• Maintenance of aftermarket ADAS are technical calibration costs and/or periodic inspection. Only when considering windshield replacements, the systems need to be recalibrated, which takes roughly 20 minutes of labor.
• Calibration of ADAS (both factory and retrofitting) will play a major role in the coming years. Other maintenance costs (i.e. repairing the system) appear to be insignificant for aftermarket products.
• Policy measures that are mentioned during the stakeholder workshop are awareness campaigns, driver trainings or creating awareness by imposing a score/rating (similar to the NCAP). Consensus on which policy measures should be advocated and on what level is currently lacking.

Benefits

Feedback from the interviews

• Warnings and advice are OK functionalities for retrofit aftermarket products
• Most promising safety benefits based on accident analysis are ISA, LDW, FCW. Also is driver distraction detection (DDR) can be promising, but depending on the implementation.
• People will use these retrofit systems, if there is not too much false warnings which annoy - this is important really important
• ISA is an additional way to inform the driver about speed limits, today these systems are not working fully, therefore not provide additional safety benefits.
• LDW is from safety perspective relevant and from cost and technical perspective feasible
• REV & TPM a both proved technology, easy to install as retrofit and also provides safety benefits
• Retrofit VIS-DET is a high priority system

Feedback from the workshop

• Regarding retrofitted and factory fitted ADAS benefits: Some stated that warning systems are less effective. However, OEMs also provide warning systems and these can be as effective as retrofitted warning systems. Although the systems should be comparable.
• Some comments regarding specific ADAS: (FCW) distinction between warning and critical warning systems, (LDW) overreliance on ADAS, Effect of ISA on non-equipped vehicle fleet, indirect effect of TPM: less people along the road with a flat tyre, which is a safety risk.

CBA

Feedback from the workshop/interviews

• “The degree of vehicles with retrofitted ADAS is currently negligible (<0.5% of fleet). And the number of retrofitted vehicles is likely to be higher for HDV and buses and coaches since these vehicle categories are relatively expensive.” Stakeholders suggest that this assumption might be oversimplified as the uptake also depends on the benefit for fleet owner. No other objections or comments are made.
Autonomous growth of ADAS is, compared to the American and Asian market, the lowest. For instance, the uptake of ADAS is roughly less than two times higher compared to Europe.

Stakeholders mention the use of insurance premiums as a means to increase the adoption of ADAS. Interviews with insurance companies indicate that there is interest (and even pilots) for this type of (voluntary) measure. Although offering large scale insurance premiums is not done in practice.

Furthermore, the different inputs regarding costs and benefits, provided by the participants, are used in the cost-benefit analysis.
GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

– by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
– at the following standard number: +32 22999696, or
– by email via: https://europa.eu/european-union/contact_en

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU publications

You can download or order free and priced EU publications from: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1952 in all the official language versions, go to EUR-Lex at: http://eur-lex.europa.eu

Open data from the EU

The EU Open Data Portal ( http://data.europa.eu/euodp/en ) provides access to datasets from the EU. Data can be downloaded and reused for free, for both commercial and non-commercial purposes.