THE FUTURE OF TRANSPORT

PUBLISHED PROJECT REPORT PPR2077

Cost and benefit analysis of new vehicle safety technologies

M Seidl, L Smith, D Palmer, C Baverstock, O Howes, J Radcliffe, B Gupta, M Jones, S Varadarajan, B But, P Martin

Report details

Report prepared for:	Department for Transport (DfT), International Vehicle Standards (IVS)		
Project/customer reference:	T0408/TETI0057		
Copyright:	© TRL Limited		
Report date:	March 2024		
Report status/version:	Final		
Quality approval:			
Cathy Booth (Project Manager)	**Cathy Booth**	Phil Martin (Technical Reviewer)	**Phil Martin**

Disclaimer

This report has been produced by TRL Limited (TRL) under a contract with Department for Transport (DfT). Any views expressed in this report are not necessarily those of Department for Transport (DfT).

The information contained herein is the property of TRL Limited and does not necessarily reflect the views or policies of the customer for whom this report was prepared. Whilst every effort has been made to ensure that the matter presented in this report is relevant, accurate and up-to-date, TRL Limited cannot accept any liability for any error or omission, or reliance on part or all of the content in another context.

When purchased in hard copy, this publication is printed on paper that is FSC (Forest Stewardship Council) and TCF (Totally Chlorine Free) registered.

Contents

Executive summary 4

1 Introduction 11

2 Vehicle technologies 12

2.1 Technologies analysed 12

2.2 Currently applicable technical regulations 13

2.3 Technical regulations considered for implementation 13

3 Cost-benefit appraisal method 15

3.1 Cost-benefit analysis 15

3.2 Impacts considered 15

3.3 Vehicle categories considered 20

3.4 Technology packages analysed 20

3.5 Appraisal parameters 21

3.6 Limitations 23

4 Summary results 25

4.1 Technology packages 25

4.2 Individual technologies 41

5 Conclusions 45

6 Acknowledgements 47

7 References 48

Appendix A Vehicle technologies – technical information 54

Appendix B Calculation methods and models 74

Appendix C Input data for impact modelling 96

Appendix D Detailed results 153

Appendix E Comparison of GB and EU cost-benefit analyses 172

Executive summary

The last 15 years have seen substantial developments in vehicle safety. Passive safety vehicle design has evolved, and new driver assistance and active safety technologies developed by vehicle manufacturers have been fitted to parts of the vehicle fleet without a legal requirement. The objective of this cost-benefit analysis (CBA) was to quantify the benefits and costs that would arise from mandating the fitment of up to 19 vehicle safety technologies (see Table 1) to new cars, vans, lorries, buses and coaches in Great Britain (GB). This will provide the Department for Transport (DfT) with an evidence base to develop policy options for ministers that are cost-effective and impactful for GB in order to enable safer and cleaner transport while causing minimal negative effects.

Table 1: Vehicle safety technologies considered for mandatory implementation in GB, vehicle categories for application and implementation years assumed for this study (new type approvals / new vehicle registrations):
■ = 2025 / 2027 ◘ = 2026 / 2029 □ = introduction not considered

Technology	Code	M_1 Car	N_1 Van	M_2 & M_3 Bus/coach	N_2 & N_3 Lorry
Advanced distraction warning	ADW	■	■	■	■
Alcohol interlock facilitation	AIF	■	■	■	■
Blind spot information	BSI	□	□	■	■
Drowsiness and attention warning	DAW	■	■	■	■
Direct vision	DIV	□	□	◘	◘
Emergency braking for cyclists	EBC	■	■	□	□
Emergency braking for pedestrians	EBP	■	■	□	□
Emergency braking for vehicles	EBV	■	■	□	□
Event data recorder	EDR	■	■	◘	◘
Emergency lane keeping	ELK	■	■	□	□
Emergency stop signal	ESS	■	■	■	■
Frontal full-width impact	FFI	■	■	□	□
Frontal off-set impact	FOI	□	■	□	□
Intelligent speed assistance	ISA	■	■	■	■
Moving off information	MOI	□	□	■	■
Pole side impact	PSI	■	■	□	□
Pedestrian windscreen impact	PWI	■	■	□	□
Reversing motion awareness	RMA	■	■	■	■
Tyre pressure monitoring	TPM	□	■	■	■

Cost-benefit analysis has been undertaken to determine the impacts that would arise from seven interventions, i.e. mandatory implementation of different technology packages (see Table 2), compared with the business-as-usual case, i.e. continued voluntary adoption of the technologies in parts of the vehicle fleet in a market environment where technologies are mandatory in the EU for the same vehicle categories.

Table 2: Technology packages analysed:
■ = technology included (for applicable vehicle categories) □ = technology not included

	ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
TP1 All technologies	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
TP2 All technologies excluding ISA	■	■	■	■	■	■	■	■	■	■	■	■	■	□	■	■	■	■	■
TP3 UNECE regulations only	□	□	■	□	■	■	■	■	■	□	■	■	■	□	■	■	■	■	■
TP4 Regulation based on pessimistic cost effectiveness*	■	■	□	■	□	□	■	■	■	■	□	□	□	□	■	□	□	□	□
TP5 Regulation based on pessimistic casualty effectiveness**	■	□	□	■	□	■	■	■	■	■	□	■	□	■	■	□	□	■	□
TP6 Vulnerable road user protection	■	□	■	■	■	■	■	□	□	□	□	□	□	■	■	□	■	■	□
TP7 Vehicle manipulation technologies	□	□	□	□	□	■	■	■	□	■	□	□	□	□	□	□	□	□	□

*: Technologies with individual BCR ≥ > 1 in Pessimistic scenario

**: Technologies with killed or seriously injured (KSI) casualties prevented ≥ 100 (over entire appraisal period) in Pessimistic scenario

The primary purpose of the technologies considered is to reduce road collisions and casualties, but two technologies (intelligent speed assistance (ISA) and tyre pressure monitoring (TPM)) would also have environmental and traffic benefits. Two models were used in conjunction to quantify and monetise the impacts listed in Table 3: The Clustered

Impact Appraisal Model (CIAM), bespoke software developed as part of the iMAAP suite, and the Economic Appraisal Model (EAM), implemented in Excel, both of which were developed in the context of this study and designed to conform to best practice and guidance set out in both the Government's Transport Analysis Guidance (TAG) and Green Book.

Table 3: Primary impacts modelled for CBA

Category	Impacts
Safety impacts	Casualties
	Collisions
Environmental impacts	CO_2 emissions
	NO_x emissions
	PM_{10} emissions
Traffic impacts	Journey time
Cost impacts	Fuel/energy consumption
	Technology fitment costs
	Technology maintenance and repair costs
Indirect tax revenues	Fuel duty
	Value Added Tax (VAT)

The following appraisal parameters, informed by the Green Book, were applied for the CBA:

- Appraisal period: 2025 to 2039 (15 years, which fully captures one fleet replacement cycle for cars)
- Base year (for discounting): 2025
- Price base year (for deflating): 2025
- Discount rate (willingness to pay component of casualty valuations): 1.50%
- Discount rate (all other values): 3.50%

Limitations of the methods applied were:

- Uncertainties relating to future projections of voluntary technology uptake, fleet size, fleet composition and casualty baselines, which are all influenced by a variety of external factors. The effects of varying future projections were explored by sensitivity analysis.
- Uncertainties relating to effectiveness estimates of some technologies where no or no UK-/GB-specific studies were available, and relating to fitment costs in general, where available data was scarce due its commercially sensitive nature. These factors were also varied in the sensitivity analysis.

- Casualties related to minibuses (ca. 0.3% of KSI casualties) were not included for benefit calculations due to data limitations in the vehicle fleet data used. The reported total numbers of casualties prevented therefore tend to be under-estimates.
- Impacts of the interventions on vehicle insurance costs were not modelled because no evidence was identified that allowed to determine how insurance premiums were affected by vehicle safety technologies in the past or could be affected in the future.
- The safety effects modelled for event data recorder (EDR) and alcohol interlock facilitation (AIF) are indirect. Their realisation, respectively, depends on EDR data being used successfully in future research and the establishment of an alcohol interlock fitment programme in GB.

The main results of this study are summarised in Table 4. Note that the results indicate the expected effect of mandatory technology implementation over and above what would happen without intervention; for instance, casualties prevented over the 15-year period in addition to those prevented by voluntary technology fitment over the same time period.

Table 4: Main results for technology packages: Benefit-cost ratio (BCR), equivalent annual net direct cost to business (EANDCB), number of killed and seriously injured (KSI) casualties prevented over appraisal period, and share of baseline KSI casualties prevented in the final year of the appraisal period

		BCR	EANDCB	KSIs prevented (2025–2039)	Share of base-KSIs prevented (2039)
TP1	**All technologies**	5.4	£98.2m	14,406	6.7%
TP2	**All technologies excluding ISA**	4.3	£91.2m	9,062	4.2%
TP3	**UNECE regulations only**	4.4	£53.7m	5,667	2.7%
TP4	**Regulation based on pessimistic cost effectiveness**	5.6	£63.3m	7,460	3.4%
TP5	**Regulation based on pessimistic casualty effectiveness**	5.7	£92.1m	13,943	6.5%
TP6	**Vulnerable road user protection**	5.2	£62.9m	9,741	4.5%
TP7	**Vehicle manipulation technologies**	5.0	£48.1m	5,141	2.6%

Figure 1 presents an overview of the cost effectiveness and casualty impact of each technology, were it to be mandated individually, in order to indicate the scale of each technology's contribution to the impact of packages. Note that the impacts of technology packages cannot be derived by summing up the impacts of individual technologies because the modelling considers overlaps in the casualty target populations and costs in order to avoid overestimating impacts.

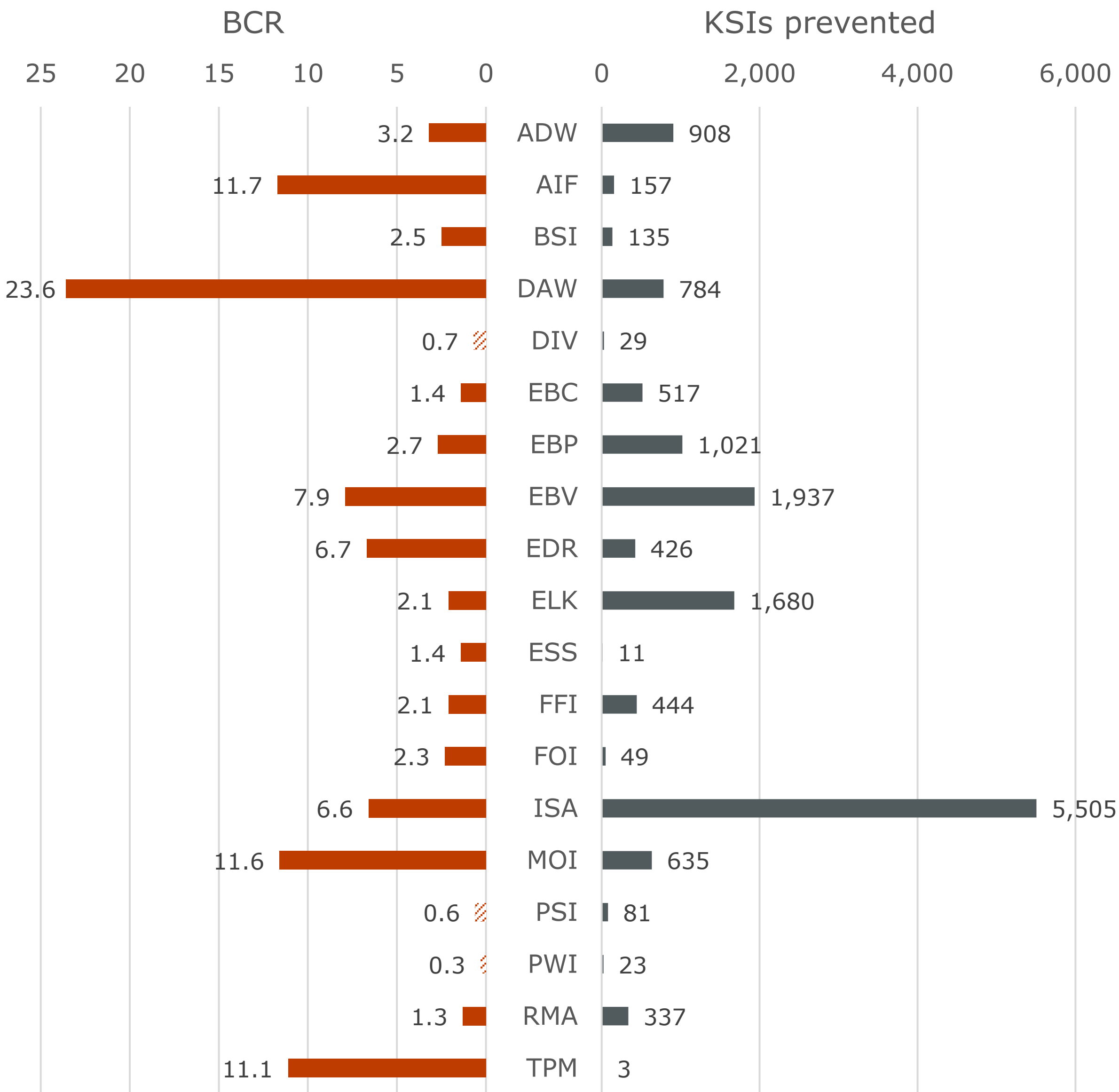


Figure 1: Main results for individual technologies: Overview of benefit-cost ratios (BCRs) and killed and seriously injured (KSI) casualties prevented by technologies when mandated individually; hatched orange bars indicating BCR < 1 (DIV, PSI, PWI)

From this CBA it was concluded that all seven technology packages bring benefits outweighing the costs with BCRs of 4.3 or higher, i.e. provide very high value for money, and take advantage of synergies between different technologies, such as lower costs due to sensor sharing, when implemented jointly.

Two packages stand out with a very high level of casualty benefits (see Figure 2) – TP5 and TP1 both bring casualty benefits in the region of 14,000 KSIs prevented over the 15-year appraisal period. Understandably, the best performing technology package in terms of number of KSIs prevented is that which includes every single technology (TP1) at 14,406. In the final year of the appraisal period TP1 prevents the equivalent of 6.7% of the KSI casualties expected to be reported in GB in absence of the technologies. This is very closely followed by TP5 (regulation based on pessimistic casualty effectiveness), which includes only 11 of the 19 technologies and prevents only 463 fewer KSIs (ca. 3% fewer). Both packages are among the ones providing the highest value for money, with TP5 being the most cost effective in the field, at a BCR of 5.7 compared to 5.4 for TP1. Both packages, however, also create the highest cost to business in the field with EANDCBs at £98.2 million (TP1) and £92.1 million (TP5).

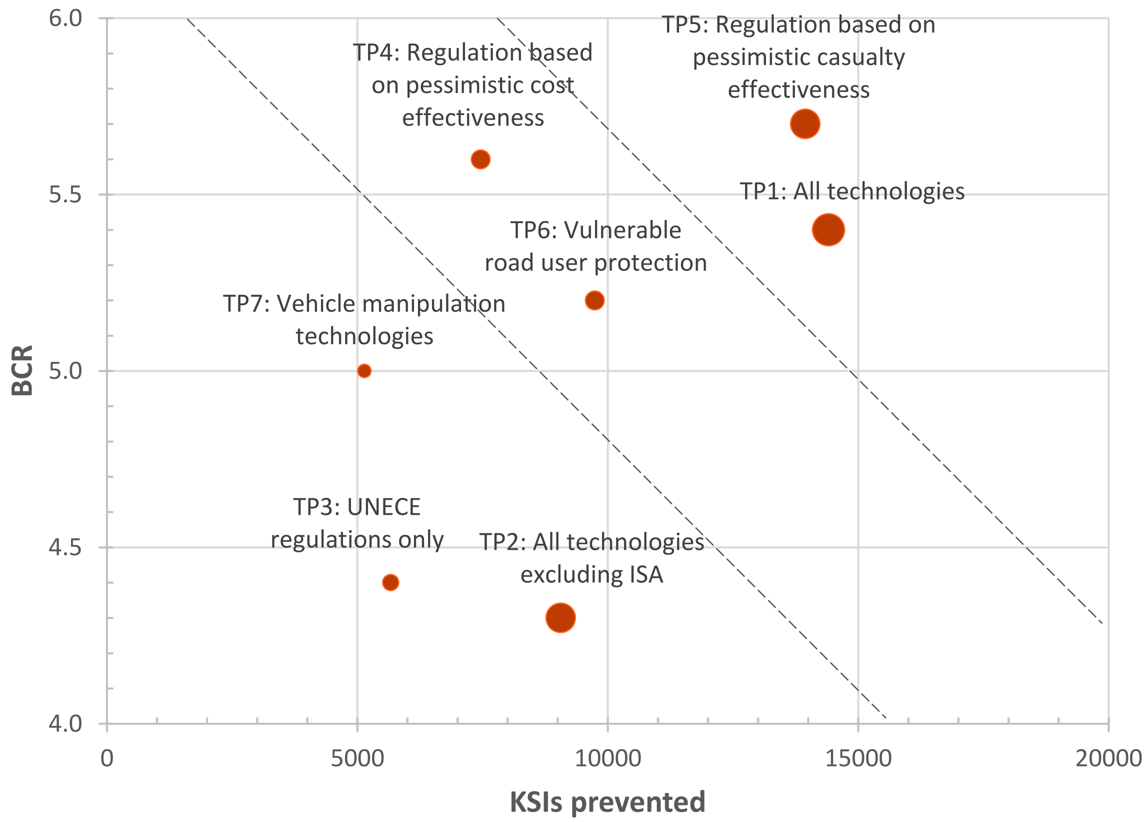


Figure 2: Comparison of benefit-cost ratios (BCR, vertical axis), killed and seriously injured (KSI) casualties prevented (horizontal axis), and equivalent annual net direct cost to business (EANDCB, indicated by marker size) of the interventions studied; dashed lines indicating different bands of BCR and KSI effectiveness

Two further packages, TP4 (regulation based on pessimistic cost effectiveness) and TP6 (vulnerable road user protection), are similar to TP1 and TP5 in terms of value for money but create lower cost to business with EANDCBs in the region of £63 million. The casualty benefits are in the middle of the range with KSIs prevented at 7,460 (TP4) and 9,741 (TP6).

Each of the remaining three packages, TP2 (all technologies excluding ISA), TP3 (UNECE regulations only) and TP7 (vehicle manipulation technologies), suffer from comparative shortcomings in at least one of the dimensions considered: TP2 provides the lowest value for money in the field (BCR: 4.3); TP3 and TP7 create low casualty benefits with KSIs prevented at 5,667 and 5,141 respectively. TP3 is unique in that it is entirely based on internationally harmonised regulations and would therefore, in practice, likely allow the quickest implementation in law because no domestic technical regulations would have to be developed.

Qualitative appraisal showed that most secondary economic, social and environmental impacts lean in a beneficial direction. The strongest effects are expected with regard to journey time reliability, resources for research, active travel and access to justice (moderate beneficial effects from TP1 and TP5). For TP6 and TP7 these are expected to be weaker, with active travel being the only impact category with moderate beneficial effects. Also for TP2 and TP3 the effects are weaker with only resources for research and access to justice being appraised as moderate beneficial effects. Potential adverse secondary impacts regard affordability and accessible vehicles, with all technology packages having slight or moderate adverse effects. These effects should be considered in the context of the Public Sector Equality Duty's protected characteristics 'age' and 'disability', because affordability might affect different age groups differently and because many motorised road users with disabilities require substantial alterations to their vehicles which may involve adapting or disabling some of the vehicle technologies considered. For potential implementing legislation, it should be investigated whether targeted exemptions are required to ensure that the manufacture of accessible vehicles is not hindered.

Overall, this study concluded that TP1 (all technologies) and TP5 (regulation based on pessimistic casualty effectiveness) will offer very high value for money, create mostly beneficial secondary economic, social and environmental impacts and prevent in the region of 14,000 KSI casualties over the 15-year appraisal period compared to business as usual. TP3 (UNECE regulations only) would, in practice, likely be quicker to implement in law than other packages but it offers somewhat lower value for money and prevents considerably fewer casualties (ca. 5,700 KSIs). A staged approach to implementation could be considered, where technologies based on UNECE regulations are implemented first to realise some benefits as early as possible, and other technologies follow later once domestic technical regulations have been developed.

1 Introduction

The last 15 years have seen substantial developments in vehicle safety. Passive safety vehicle design has evolved, and new driver assistance and active safety technologies developed by vehicle manufacturers have been fitted to parts of the vehicle fleet without a legal requirement. The European Union (EU) has mandated 19 of these new safety technologies to be fitted to new cars, vans, lorries, buses and coaches – for the trading bloc, this was the most casualty-effective of three policy options considered for a cost-benefit analysis (CBA) in 2017 (Seidl M, 2017), while also being cost-beneficial compared to voluntary fitment.

Great Britain (GB)[1] is different to the average of EU-27: Road casualty rates in GB are comparatively low; infrastructure standards differ, which presents different safety challenges than in other countries; and the vehicle fleet composition and average age are different. This presents an opportunity to tailor a bespoke package of vehicle safety technologies to address the specific situation in GB.

The objective of this GB CBA was to quantify and monetise the benefits (road safety and wider impacts) and costs that would arise from mandatory fitment of each of the 19 technologies and various combinations thereof compared with business as usual (continued voluntary adoption of the technologies in parts of the vehicle fleet in absence of regulation). This will provide the Department for Transport (DfT) with an evidence base to develop policy options for ministers that are cost-effective and impactful for GB to enable safer and cleaner transport while causing minimal negative effects.

[1] Note: Through the Northern Ireland Protocol to the Brexit withdrawal agreement, the relevant EU regulations already apply for the Northern Ireland market, which is why this analysis focuses on GB only.

2 Vehicle technologies

2.1 Technologies analysed

Table 5 provides an overview of the 19 new vehicle safety technologies in scope for this study and the vehicle categories and earliest years for which new implementation is considered. (Note: The three-letter 'code' given is used throughout the report as shorthand when referring to the technologies.) The technologies and applicable vehicle categories are equivalent to those introduced in the EU via the General Safety Regulation (EU) 2019/2144 ('GSR') although the number of technologies differs from that in the EU cost-effectiveness assessment because, for instance, emergency braking for pedestrians and cyclists are treated as separate technologies.

Table 5: Overview of vehicle technologies considered for mandatory implementation in GB (in alphabetical order). Vehicle categories for application and implementation years assumed for this study (new type approvals / new vehicle registrations): ■ = 2025 / 2027 ◘ = 2026 / 2029 □ = introduction not considered

Technology	Code	M_1 Car	N_1 Van	M_2 & M_3 Bus/coach	N_2 & N_3 Lorry
Advanced distraction warning	ADW	■	■	■	■
Alcohol interlock facilitation	AIF	■	■	■	■
Blind spot information	BSI	□	□	■	■
Drowsiness and attention warning	DAW	■	■	■	■
Direct vision	DIV	□	□	◘	◘
Emergency braking for cyclists	EBC	■	■	□	□
Emergency braking for pedestrians	EBP	■	■	□	□
Emergency braking for vehicles	EBV	■	■	□	□
Event data recorder	EDR	■	■	◘	◘
Emergency lane keeping	ELK	■	■	□	□
Emergency stop signal	ESS	■	■	■	■
Frontal full-width impact	FFI	■	■	□	□
Frontal off-set impact	FOI	□	■	□	□
Intelligent speed assistance	ISA	■	■	■	■
Moving off information	MOI	□	□	■	■
Pole side impact	PSI	■	■	□	□
Pedestrian windscreen impact	PWI	■	■	□	□
Reversing motion awareness	RMA	■	■	■	■
Tyre pressure monitoring	TPM	□	■	■	■

Note that:

- Alcohol interlock facilitation (AIF) ensures that vehicles are technically capable of being fitted with an alcohol interlock, but it does not require vehicles to be equipped with such interlocks. To realise the casualty benefits of AIF, an alcohol interlock fitment programme (e.g. as part of rehabilitation programmes or following court orders) would be required for GB.
- Intelligent speed assistance (ISA) can be implemented as a warning or a speed control system at the manufacturer's choice. ISA can be deactivated for the duration of a journey and a speed control system can always be overridden by the driver (e.g. by pressing the accelerator harder or deeper).

2.2 Currently applicable technical regulations

The applicable type-approval requirements for GB are set out in Retained Regulation (EU) 2018/858[2] and Retained Regulation (EU) 661/2009[3]. Most of the technologies under consideration would be newly introduced into GB regulation, i.e. no regulation applies for the no-action scenario. The exceptions to this are frontal off-set impact and pedestrian protection, where regulations already apply for the no-action scenario as detailed in Table 6.

Table 6: Overview of current technical regulations

Technology	Technical regulations	Notes
FOI	UN Regulation No. 94, 03 Series of Amendments	Already applies to category M_1 according to R661/2009. Supplement 2 (which entered into force in 2021 and therefore applies for the no-action scenario) extended the scope to vehicles of a gross vehicle mass up to 3,500 kg. The analysis considers extending this regulation to N_1 vehicles, for which it does not currently apply.
PWI	Regulation (EC) No 78/2009, as amended by Council Regulation (EU) No 517/2013	Pedestrian protection applies to M_1 and N_1 according to R2018/858 but it does not include pedestrian windscreen impact protection, which is considered in this analysis.

2.3 Technical regulations considered for implementation

Table 7 provides an overview of the technical regulations (including the relevant level of amendment) that would be applicable if implemented for each of the vehicle technologies in scope of this study. The technical requirements set out in these regulations provide the basis for cost, target population and safety and environmental effectiveness estimates to input into the cost-benefit calculations. Summaries of the technical requirements can be found in Appendix A.1.

[2] https://www.legislation.gov.uk/eur/2018/858/annex/II

[3] https://www.legislation.gov.uk/eur/2009/661/annex/IV

Table 7: Overview of future technical regulations

Technology	Technical regulations
ADW	Commission Delegated Regulation (EU) on ADDW (regulation not yet published; latest draft requirements specified in document C(2023) 4523 Final)
AIF	Commission Delegated Regulation (EU) 2021/1243
BSI	UN Regulation No. 151, Original Version
DAW	Commission Delegated Regulation (EU) 2021/1341
DIV	UN Regulation No. 167, Original Version
EBC	UN Regulation No. 152, 02 Series of Amendments
EBP	UN Regulation No. 152, Original Version
EBV	UN Regulation No. 152, Original Version
EDR	M_1, N_1: UN Regulation No. 160, 01 Series of Amendments & Commission Delegated Regulation (EU) 2022/545 M_2, M_3, N_2, N_3: No final requirements yet
ELK	Commission Implementing Regulation (EU) 2021/646
ESS	UN Regulation No. 48, 07 Series of Amendments
FFI	UN Regulation No. 137, 02 Series of Amendments
FOI	UN Regulation No. 94, 04 Series of Amendments
ISA	Commission Delegated Regulation (EU) 2021/1958
MOI	UN Regulation No. 159, Original Version
PSI	UN Regulation No. 135, 01 Series of Amendments
PWI	UN Regulation No. 127, 03 Series of Amendments; *note that this exceeds the level currently applied in the EU, that is the 02 Series of Amendments which does not include pedestrian windscreen impact protection*
RMA	UN Regulation No. 158, Original Version
TPM	UN Regulation No. 141, 01 Series of Amendments

3 Cost-benefit appraisal method

3.1 Cost-benefit analysis

Cost-benefit analysis (CBA) has been undertaken to determine the impacts that would arise from mandatory implementation for new GB vehicles of each proposed technology, or combinations thereof, compared with business as usual (continued voluntary adoption of the technologies in parts of the vehicle fleet in absence of regulation). Note that the reported impacts (in both benefits and costs) describe the effect legislation would have over and above what is expected to happen without intervention, e.g. additional road casualties prevented by those vehicles which would not have been fitted voluntarily.

Two models were used in conjunction to conduct the CBA for primary impacts: The Clustered Impact Appraisal Model (CIAM), bespoke software developed as part of the iMAAP suite, and the Economic Appraisal Model (EAM), implemented in Excel. CIAM and EAM were developed in the context of this study and designed to conform to best practice and guidance set out in both the Government's Transport Analysis Guidance (TAG) and Green Book. CIAM quantifies all impacts of the technologies, EAM performs the economic analysis of these forecast impacts. EAM uses the GDP deflator to address the impact of inflation and the appropriate discount rate to accommodate social time preference. Refer to Appendix B for more information on the calculation methods and software models.

Secondary impacts, i.e. those which are of less importance and/or for which sufficient data or valuations were unavailable to undertake a quantitative approach, were appraised in a qualitative manner. Potential secondary economic, environmental, social and public accounts impacts were identified by an expert panel and the associated causative vehicle technologies were collated. Expert judgement was then used to assess each impact on a seven-point scale of beneficial, neutral or adverse in accordance with TAG appraisal guidance. For the aggregate appraisal of technology packages, impacts were assessed as 'neutral' where no causative technologies were contained in a package, or the assessment was moderated where only some but not all causative technologies were contained. All secondary impacts identified were also assessed for their potential relevance for the Public Sector Equality Duty (PSED), which requires public authorities, in carrying out their functions, to have due regard to the need to achieve the objectives set out under s149 of the Equality Act 2010, including to advance equality of opportunity between persons who share a protected characteristic and persons who do not share it. The nine protected characteristics defined in the Act are: age, being pregnant or on maternity leave, disability, race including colour, nationality, ethnic or national origin, religion or belief, sex, sexual orientation, gender reassignment, and being married or in a civil partnership.

3.2 Impacts considered

The primary purpose of the vehicle safety technologies considered is to reduce road collisions and casualties (among both vehicle occupants and vulnerable road users (VRUs), i.e. pedestrians and cyclists). However, implementing the technologies will have a range of other impacts that need to be taken into account when undertaking CBA. All of the proposed technologies could affect the cost of new vehicles and their ongoing maintenance and repair costs, so the analysis needs to consider costs to business and private users.

A high-level assessment was undertaken to identify which impacts were likely to be both potentially significant and quantifiable, taking account of the published evidence available and project resources. The impacts taken forward for quantitative analysis in the model are shown in Table 8.

Table 8: Impacts considered for CBA modelling

Category	Impacts	Relevant technologies
Safety impacts	Casualties	All technologies
	Collisions	ADW, AIF, BSI, DAW, DIV, EBC, EBP, EBV, ELK, ESS, ISA, MOI, RMA, TPM
Environmental impacts	CO_2 emissions	ISA, TPM
	NO_x emissions	ISA
	PM_{10} emissions	ISA, TPM
Traffic impacts	Journey time	ISA
Cost impacts	Fuel/energy consumption	ISA, TPM
	Technology fitment costs	All technologies
	Technology maintenance and repair costs	BSI, EBC, EBP, EBV, ELK, ISA, MOI, RMA
Indirect tax revenues	Fuel duty	ISA, TPM
	Value Added Tax (VAT)	ISA, TPM

Some of the technologies are likely to affect the operation and performance of vehicles. In particular:

- By alerting drivers or actively reducing driving speeds when the speed limit is being exceeded, intelligent speed assistance (ISA) affects how vehicles are driven. This has potential implications for fuel consumption, NOx and PM emissions, noise and traffic flow. Changes in fuel consumption will also have cost implications for the users as well as greenhouse gas emissions (e.g. CO_2).
- Tyre pressure monitoring (TPM) would be expected to reduce the proportion of vehicles with under-inflated tyres, which should reduce fuel consumption and consequently greenhouse gas emissions and user costs. Under-inflation also leads to greater tyre wear, so TPM would have implications for particulate matter emissions (e.g. PM_{10}) from tyres.

Cost impacts on insurance, such as potentially reduced premiums due to reduced collision numbers, were considered for inclusion. However, the evidence review did not yield sources to confirm that this should be expected, which is why insurance cost impacts were not taken forward in the modelling (see Appendix C.2.7). Other potential impacts were identified for further qualitative investigation in the literature review, but not included in the model, because of limited availability of evidence and a requirement for complex modelling of local impacts (e.g. noise), which would exceed the scope of the study. Vehicle emissions were considered only in terms of impacts on total emissions rather than on modelled concentrations at a local level. Particulates released by tyre and brake wear are known to affect water quality, however this was not included in the quantitative analysis.

One area where some of these technologies could have wider benefits is in helping to make the roads safer and more comfortable for VRUs. For instance, intelligent speed assistance (ISA) could aid drivers in adhering to 20 mph speed limits in areas where they apply and reduce the need for some infrastructure changes, such as road humps. Some technologies could therefore act as enablers of modal shift to active modes, with consequent environmental and social benefits. However, given the limited evidence and complex modelling required to quantify indirect benefits like these, only a limited, qualitative, assessment was made, as part of the evidence review.

A summary of the impacts considered, and the approach taken, is given in Table 9, grouped using the TAG top-level categories:

- Economic (including the costs to businesses of installing and operating new technologies in their vehicles)
- Environmental (including the impacts on greenhouse gas emissions and tailpipe emissions such as Carbon Dioxide (CO_2), Nitrogen Oxides (NOx) and Particulate Matter (PM))
- Social (including casualties and cost impacts on private road users)
- Public Accounts (including impacts on the broader transport budget and on indirect tax revenues)

Impacts marked as ‘quantitative’ type of assessment in the table were modelled in CIAM and EAM; those marked as ‘qualitative’ were appraised qualitatively as secondary impacts.

Table 9: Summary of impacts considered by TAG category

Impact category	Impact subcategory	Potential impact from technologies under consideration	Relevant technologies	Type of assessment
Economic	Business users & transport providers (TAG Unit A1.3; table A1.2.1)	Cost impacts on GB manufacturers for vehicles sold in GB as a result of technologies, fuel/energy consumption, journey times	All technologies	Quantitative (technology costs, fuel/energy and journey time impacts)
	Reliability impact on Business users (TAG Unit A1.3; table A1.2.2)	Secondary impact on journey time reliability from reduced collisions and breakdowns	All technologies	Qualitative
	Regeneration	No impact from technologies	–	–
	Wider Impacts	Enhanced technological capabilities of supply chain for automated driving, resources for research	BSI, EBC, EBP, EBV, ELK, ISA (technological capabilities) EDR (resources for research)	Qualitative
Environmental	Noise	Very minor/negligible/localised impact on traffic noise from technologies affecting driver behaviour	ISA, TPM	Qualitative
	Air Quality	Changes in emissions arising from changes in vehicle speed and traffic flow	ISA, TPM	Quantitative
	Greenhouse gases	Changes in fuel efficiency arising from changes in vehicle speed and traffic flow, and from maintaining correct tyre pressure	ISA, TPM	Quantitative
	Landscape	No impact from technologies	–	–
	Townscape	No impact from technologies	–	–
	Historic Environment	No impact from technologies	–	–
	Biodiversity	No impact from technologies	–	–
	Water Environment	Changes in water pollution through contaminants from tyre and brake pad wear entering watercourse via surface water	TPM	Qualitative
Social	Commuting and Other users	Impact from technologies due to reduced collision and breakdown incidents, fuel/energy costs and journey time	All technologies	Quantitative (fuel/energy and journey time)
	Reliability impact on Commuting and Other users	Secondary impact on journey time reliability from reduced collision and breakdown incidents	All technologies	Qualitative

Impact category	Impact subcategory	Potential impact from technologies under consideration	Relevant technologies	Type of assessment
	Physical activity	Safer roads may encourage active travel thereby increasing road users' level of physical activity	All technologies	Qualitative
	Journey quality	Secondary impact on journey time reliability from reduced collision and breakdown incidents, affecting tension and anxiety experienced about journey times	All technologies	Qualitative
	Accidents	Reduced accidents and reduced severities	All technologies	Quantitative (avoided fatal, serious, slight and damage-only collisions and avoided killed, seriously injured and slightly injured casualties)
	Security	Negligible impact on crime from technologies, access to justice	AIF, ISA (crime) EDR (access to justice)	Qualitative
	Access to services	Potential implications for the production of accessible vehicles for disabled users	ADW, DAW, EBC, EBP, EBV, ELK, FFI, ISA, PSI, RMA	Qualitative
	Affordability	Potential purchasing and lifetime cost implications, depending on whether GB manufacturers pass on the costs to GB customers	All technologies	Qualitative
	Severance (separation of communities)	No impact from technologies	–	–
	Option and non-use values (changes to available transport in areas)	No impact from technologies	–	–
Public Accounts	Cost to Broad Transport Budget (A1.1: split between local and central govts)	No impact from technologies	–	–
	Indirect Tax Revenues	Affected by changes in VAT and duty from impacts on fuel consumption	ISA, TPM	Quantitative

3.3 Vehicle categories considered

Four groups of vehicle categories have been analysed, made up of the six categories for motor vehicles with four or more wheels defined in Retained Regulation (EU) 2018/858:

- M_1 – Passenger cars
- M_2 & M_3 – Buses and Coaches
- N_1 – Vans
- N_2 & N_3 – Lorries

The results of the study are reported as totals, i.e. representing the combined impacts across all of these vehicle categories. Selected results are further disaggregated to inform on the separate impacts per vehicle category group. Note that the way collisions which involve vehicles from more than one group (e.g. a lorry to car impact) are modelled does not allow perfect disaggregation and the results per vehicle category group should be understood to give only an indication of how the impacts are distributed.

Note that the group M_2 & M_3 was originally intended to capture minibuses (vehicles with 8 to 16 passenger seats). However, during the course of the study it was identified that the required forecast data produced by DfT's National Transport Model (NTM) and Road Carbon and Fuel Fleet (RoCaFF) model (vehicle fleet size, vehicle new sales, annual mileage, etc.) includes minibuses in the group 'vans'. The contribution of minibuses to GB road casualties is small (it was found that ca. 0.3% of killed or seriously injured casualties were minibus occupants or VRUs hit by a minibus); nevertheless, if unaddressed this would introduce inaccuracy because the safety technologies considered for vans are not identical to those for minibuses. As these models cannot be changed, it was decided to address the inaccuracy for this CBA in a way that ensures the results are conservative estimates, i.e. tend to underestimate the benefit-cost ratio (BCR). This was achieved by removing casualties involving minibuses from the collision data analysed in this study (i.e. no casualty benefits modelled for these), while costs are still counted under the group 'vans' (because the number of minibuses could not be disaggregated from vans in the RoCaFF model).

3.4 Technology packages analysed

All 19 vehicle technologies individually and 7 packages including multiple technologies were analysed for this study. Table 10 shows the names and identification numbers assigned to each of these packages, which are used as identifiers in the results section, and the technologies contained. The technologies listed were included for all applicable vehicle categories and from the relevant introduction dates, as specified in Table 5, Section 2.1.

Table 10: Technology packages analysed:
■ = technology included □ = technology not included

	ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
TP1 All technologies	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
TP2 All technologies excluding ISA	■	■	■	■	■	■	■	■	■	■	■	■	■	□	■	■	■	■	■
TP3 UNECE regulations only	□	□	■	□	■	■	■	■	■	□	■	■	■	□	■	■	■	■	■
TP4 Regulation based on pessimistic cost effectiveness*	■	■	□	■	□	□	■	■	■	■	□	□	□	□	■	□	□	□	□
TP5 Regulation based on pessimistic casualty effectiveness**	■	□	□	■	□	■	■	■	■	■	□	■	□	■	■	□	□	■	□
TP6 Vulnerable road user protection	■	□	■	■	■	■	■	□	□	□	□	□	□	■	■	□	■	■	□
TP7 Vehicle manipulation technologies	□	□	□	□	□	■	■	■	□	■	□	□	□	□	□	□	□	□	□

*: Technologies with individual BCR > 1 in Pessimistic scenario (see Section 3.5 and Appendix D.4)

**: Technologies with killed or seriously injured (KSI) casualties prevented ≥ 100 (over entire appraisal period) in Pessimistic scenario

3.5 Appraisal parameters

This section summarises the main appraisal parameters applied; detailed input data for CIAM and EAM on aspects such as casualty target populations, technology effectiveness and cost estimates, and expected voluntary fitment rates can be found in Appendix C.

The study used an appraisal period of 15 years, extending from 2025 through to 2039 for all analyses. The start year was chosen to coincide with the earliest technology introduction date (see Section 3.3). The duration was based on GB's vehicle fleet renewal cycle and captures about one replacement cycle for cars which have an average age at scrappage of 14.2 years (SMMT, 2019) and are the dominant category for impacts based on their numbers.

For the economic calculations, the year 2025 was used as base year (the year values are discounted to) and as price base year (the year values are deflated to). Adjustments for the impacts of inflation and social time preference have been included. Inflation adjustments were based on the GDP Deflator. Social time preference effects have been based on a discount rate of 3.5% in general with the exception for risk to life impacts (specifically the willingness to pay component of casualty valuations) for which a rate of 1.5% was applied.

Three sensitivity scenarios were calculated for each technology package (Central Estimate, Optimistic scenario and Pessimistic scenario) by varying the input data for the casualty baseline (high, medium or low number of casualties, see Appendix C.5.1), the technology effectiveness (high, medium or low effectiveness, see Appendix C.6.1) and the fitment and maintenance costs (high, medium or low technology costs, see Appendix C.3).

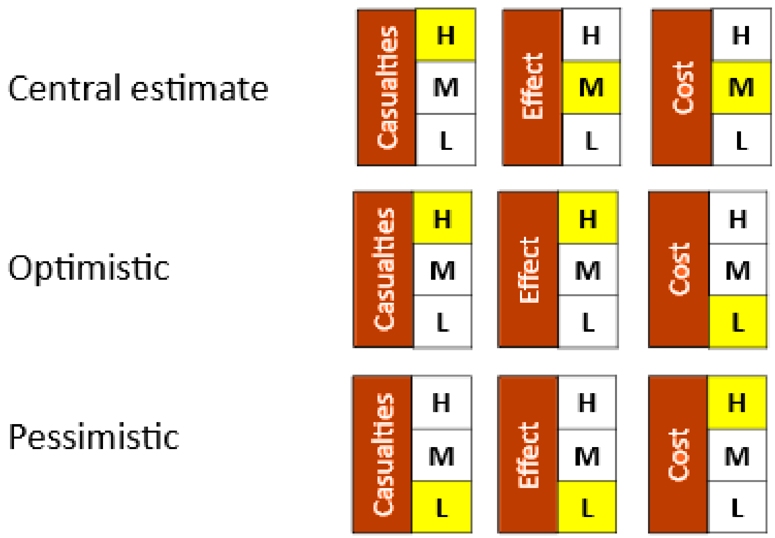


Figure 3: Sensitivity scenarios calculated; yellow highlighting shows input data range for casualty baseline, technology effectiveness and technology costs (high, medium, low)

The Central Estimate applies the casualty baseline which is considered most likely to occur (i.e. the high casualty baseline derived from the vehicle-led decarbonisation scenario in the NTM, representing a situation where the zero emission vehicle mandate is implemented) and the best estimates from published research and stakeholder consultation for technology effectiveness and costs.

The Optimistic scenario applies the same casualty baseline assumption and explores the impact of the optimistic range for both technology effectiveness and costs, i.e. assuming high effectiveness and low cost. In this scenario all three sensitivity parameters are set to result in a high BCR.

The Pessimistic scenario applies the lowest casualty baseline that is reasonably expected (derived from the mode-balanced decarbonisation scenario in the NTM) while exploring the pessimistic range for both technology effectiveness and costs. In this scenario all three sensitivity parameters are set to result in a low BCR.

3.6 Limitations

The limitations of the methods applied for this study were:

- The business-as-usual case, in particular the level of future technology uptake in absence of GB legislation, is uncertain and strongly influenced by the EU mandate to fit the technologies, including to right-hand drive vehicles produced for Ireland. If all future new vehicles in GB would be equipped, legislation would have no measurable added effect. For this study, a high but not universal level of voluntary fitment was assumed, which was taken into account for the modelling of both, benefits and costs. See Appendix C.3.3 for the underlying rationale.
- Similarly, the future projections of baseline casualty numbers strongly affect the results, with more future casualties allowing for greater benefits per equipped vehicle. Future casualty trends are highly uncertain because they are influenced by a variety of factors including vehicle fleet size and modal shift, road infrastructure design and maintenance, changes in driver behaviour and impacts of automated driving. For this study, casualty baselines were created with the best available research methods (see Appendix C.5.1) and the effects of varying baselines were explored by sensitivity analysis.
- Future projections of fleet size and composition, which affect casualty and cost estimates, are uncertain because they are influenced by policy decisions (such as the zero emission vehicle mandate or policies to encourage modal shift) and technical developments, the effect of which may not yet be fully foreseen. Fleet projections from the RoCaFF model were used as the most reliable source available (see Appendix C.4). The effects of different fleet scenarios were incorporated in the sensitivity analysis.
- RoCaFF fleet projections do not allow to disaggregate minibuses from the group ‘vans’ (see Section 3.3), but both categories should not be analysed in conjunction because different technologies apply to either vehicle category. The contribution of minibuses to GB road casualties is small (ca. 0.3% of KSI casualties) and it was decided to remove minibus-related casualties from the target population numbers in order to arrive at conservative total BCR estimates, i.e. the reported total numbers of casualties prevented tend to be under-estimates.
- Technology effectiveness estimates were generally extracted from sufficiently recent, high-quality published studies. Great care was taken to identify all pertinent literature but the possibility that studies were missed in the search cannot be excluded and further newer data may impact the study findings. Where possible, data from UK-/GB-specific studies was used to reflect the local road and driver behaviour environment; however, for many technologies only EU or US studies were identified and used as the best available substitutes (AIF, DAW, EBC, EBP, EBV, ELK,

FOI and PSI). For five technologies (ADW, EDR, ESS, PWI and TPM), no studies were identified, and expert estimates previously performed for the EU CBA (Seidl M, 2017) had to be used. The study used for intelligent speed assistance (ISA) was UK-specific but the underlying trial data was almost two decades old; the effectiveness estimates were therefore corrected to reflect changes in baseline speed limit compliance that occurred during this period, thereby scaling down the benefits modelled. See Appendix C.6 for more information on literature selection. The effects of varying technology effectiveness were explored by sensitivity analysis.

- Technology fitment costs are the highest cost contributor of the interventions studied. Estimates were derived under consideration of stakeholder-provided information (see Appendix C.3.2), but must be considered uncertain because, due to the commercially sensitive nature, only limited amounts of data were available. The effects of varying fitment costs were explored by sensitivity analysis.
- Impacts of the interventions on vehicle insurance costs were not modelled because no evidence was identified that allowed to determine how insurance premiums were affected by vehicle safety technologies in the past or could be affected in the future.
- The safety effects modelled for event data recorder (EDR) and alcohol interlock facilitation (AIF) are indirect. EDR does not actively prevent collisions or casualties (except for a potential small moderating effect on driver behaviour), but EDRs would provide better collision data for road safety researchers, vehicle manufacturers and suppliers, which in turn could lead to more effective future road and vehicle safety policies and safer vehicle designs if research is performed on that data. AIF ensures that vehicles are technically capable of being fitted with an alcohol interlock, but it does not require vehicles to be equipped with such interlocks. To realise the casualty benefits of AIF, an alcohol interlock fitment programme (e.g. as part of rehabilitation programmes or following court orders) would be required for GB.

4 Summary results

This section summarises the key results on primary impacts from both models, CIAM and EAM, and the qualitative appraisal of secondary impacts. These summary results are concerned with the Central Estimate. Full results, including environmental and journey time impacts, Pessimistic and Optimistic scenarios, and additional detail on secondary impacts are reported in Appendix D.

4.1 Technology packages

Seven different combinations of technologies ('technology packages') have been analysed. Refer to Section 3.4 for details on which technologies are contained in each package.

- TP1: All technologies
- TP2: All technologies excluding ISA
- TP3: UNECE regulations only
- TP4: Regulation based on pessimistic cost effectiveness
- TP5: Regulation based on pessimistic casualty effectiveness
- TP6: Vulnerable road user protection
- TP7: Vehicle manipulation technologies

4.1.1 Overview

The main results found for the seven technology packages are summarised in Table 11.

Table 11: Benefit-cost ratio (BCR), equivalent annual net direct cost to business (EANDCB), number of killed and seriously injured (KSI) casualties prevented over appraisal period, and share of baseline KSI casualties prevented in the final year of the appraisal period

		BCR	EANDCB	KSIs prevented (2025–2039)	Share of base-KSIs prevented (2039)
TP1	**All technologies**	5.4	£98.2m	14,406	6.7%
TP2	**All technologies excluding ISA**	4.3	£91.2m	9,062	4.2%
TP3	**UNECE regulations only**	4.4	£53.7m	5,667	2.7%
TP4	**Regulation based on pessimistic cost effectiveness**	5.6	£63.3m	7,460	3.4%
TP5	**Regulation based on pessimistic casualty effectiveness**	5.7	£92.1m	13,943	6.5%
TP6	**Vulnerable road user protection**	5.2	£62.9m	9,741	4.5%
TP7	**Vehicle manipulation technologies**	5.0	£48.1m	5,141	2.6%

Figure 4 presents these results as a comparative overview: More cost-effective packages are shown further up, more casualty-effective packages are shown further to the right of the graph and packages creating lower cost to business have smaller markers; the dashed lines indicate different bands of BCR and KSI effectiveness.

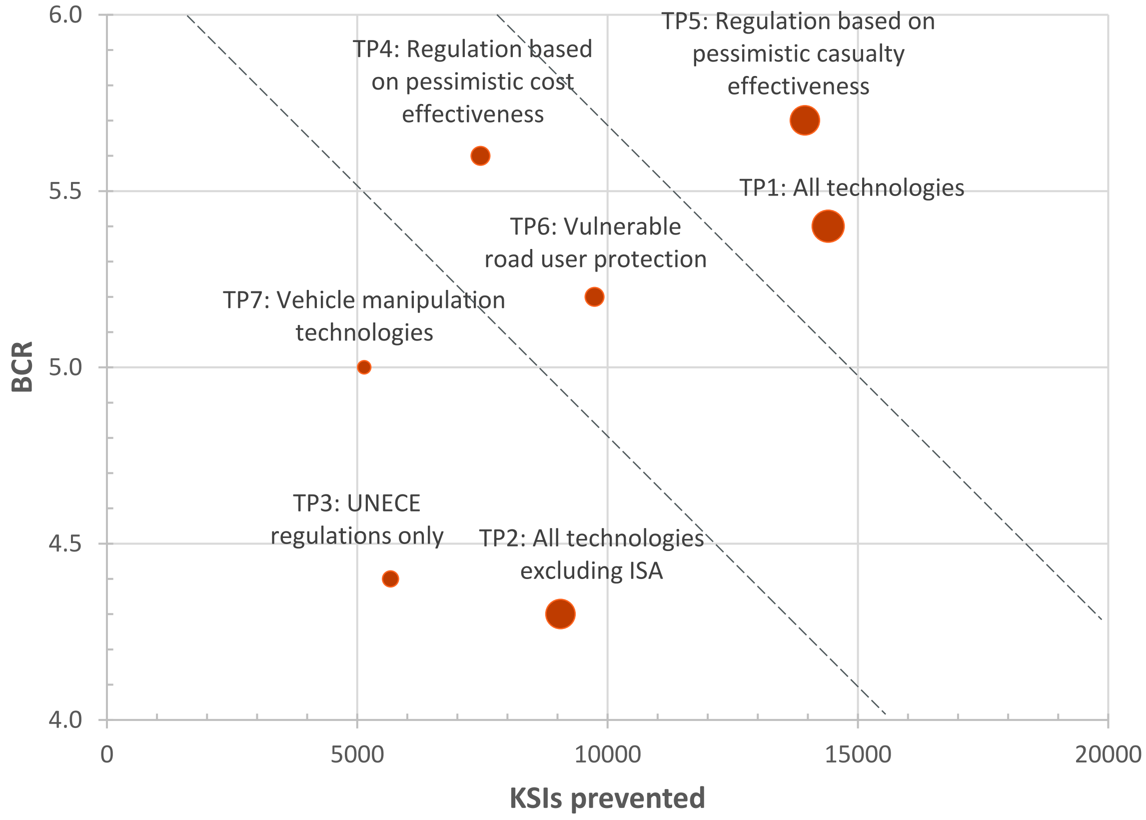


Figure 4: Overview of benefit-cost ratios (BCR), killed and seriously injured (KSI) casualties prevented, and equivalent annual net direct cost to business (EANDCB)

The following subsections present further results for each package.

4.1.2 All technologies (TP1)

Cost effectiveness and casualty impact

Table 12: Summary of key results (TP1, Central Estimate)

	KSIs prevented 2025–2039	Fitment costs (£ million)	EANDCB (£ million)	BCR
M1	10,097	1,006.9	77.2	4.8
M2M3	1,764	19.2	1.1	42.0
N1	930	144.4	7.6	3.5
N2N3	2,807	189.1	12.3	8.7
Total	**14,406**	**1,365.4**	**98.2**	**5.4**

Note that the total impacts cannot be derived by summing up the individual vehicle category results (see Section 3.3).

All technologies (TP1) was, as expected, the package with the largest impact in terms of numbers of KSIs prevented. Over the 15 years of the assessment, more than 14,400 KSIs are estimated to be prevented (see Table 12), of which just over 10,000 involved cars (M1). In other words, approximately 960 KSIs are prevented each year, including just over 670 KSIs involving cars. Over 2,800 KSIs involving lorries (N2N3) are also prevented – about 187 per year. The total costs of fitment across all vehicle types would be over £1.3 billion.

Implementing all technologies provides very high value for money[4]. Not only was the total BCR very high (at 5.4) but for each vehicle category it was at least high. The highest BCR was found for M2M3 – buses and coaches – at 42.0, which substantially exceeds the other vehicle categories. This effect is observed in all technology packages analysed and is due to the fact that buses and coaches have high baseline casualty numbers per vehicle compared to other categories: M2M3 has a baseline casualty target population two-thirds the size of N2N3 but only 10% of the new vehicle sales in the 15-year appraisal period compared to N2N3. The EU BCA (Seidl M, 2017) has also shown the highest BCRs for buses and coaches, although the effect was not as pronounced as in this GB analysis. Note that minibuses, which may have masked some of this effect in the EU CBA, were excluded from this GB CBA (see Section 3.3).

TP1 generates a very high level of total benefits over the 15-year assessment period. Nevertheless, the fitment costs are also significant – over £1.3 billion. The EANDCB is the highest of the packages at £98 million.

Secondary impacts

While the above cost-effectiveness indicators contain the dominant safety, environmental, journey time and cost impacts, the technologies also cause secondary impacts, which are of less importance and/or for which sufficient data or valuations were unavailable to undertake a quantitative approach. Secondary economic, environmental, social and public accounts impacts were assessed in a qualitative manner (see Section 3.1) on a on a seven-point scale of adverse, neutral or beneficial. The secondary impacts identified for TP1 are summarised in Table 13. Where a secondary impact potentially has relevance for the Public Sector Equality Duty (PSED), this is indicated in the table. Descriptions of the impacts and which individual technologies they arise from are provided in Appendix D.5.

[4] DfT's Value for Money Framework considers a BCR of 4 or higher as 'very high' and a BCR between 2 and 4 as 'high' (Department for Transport, 2015). BCRs of 2 or lower are considered as 'medium', 'low', 'poor' or 'very poor'.

Table 13: Summary of secondary impacts (TP1), their qualitative appraisals on seven-point scale (strongly adverse to strongly beneficial) and potential relevance for Public Sector Equality Duty (PSED)

Impacts		−3	−2	−1	0	+1	+2	+3	PSED relevant
Economic	Journey time reliability						■		No
	Technological capabilities					■			No
	Resources for research						■		No
Environmental	Traffic noise					■			No
	Water pollution					■			No
Social	Journey time reliability						■		No
	Active travel						■		No
	Crime					■			No
	Access to justice						■		No
	Affordability		■						Yes
	Accessible vehicles			■					Yes

4.1.3 All technologies excluding ISA (TP2)

Cost effectiveness and casualty impact

Table 14: Summary of key results (TP2, Central Estimate)

	KSIs prevented 2025–2039	Fitment costs (£ million)	EANDCB (£ million)	BCR
M1	6,897	845.0	71.1	4.3
M2M3	815	17.0	0.9	23.1
N1	550	121.0	9.2	2.5
N2N3	1,289	168.6	10.1	5.0
Total	**9,062**	**1,156.7**	**91.2**	**4.3**

Note that the total impacts cannot be derived by summing up the individual vehicle category results (see Section 3.3).

This package (TP2) includes eighteen individual technologies and excludes ISA. Excluding ISA inevitably reduces the total number of KSIs prevented (see Table 14) compared with TP1. Nevertheless, it remains high at over 9,000 (over 600 per year). Cars (M1) again account for the largest vehicle category, while buses and coaches (M2M3) generate the highest BCR. The BCRs are lower than for all technologies (TP1), but still indicate very high value for money, although for N1 (vans) the BCR is only high at 2.5. The total fitment costs are almost £1.2 billion. The annual costs to business are 7% less than for TP1 at £91 million.

Secondary impacts

The secondary impacts identified for TP2 are summarised in Table 15.

Table 15: Summary of secondary impacts (TP2), their qualitative appraisals on seven-point scale (strongly adverse to strongly beneficial) and potential relevance for Public Sector Equality Duty (PSED)

Impacts		**−3**	**−2**	**−1**	**0**	**+1**	**+2**	**+3**	**PSED relevant**
Economic	Journey time reliability					■			No
	Technological capabilities					■			No
	Resources for research						■		No
Environmental	Traffic noise					■			No
	Water pollution					■			No
Social	Journey time reliability					■			No
	Active travel					■			No
	Crime					■			No
	Access to justice						■		No
	Affordability		■						Yes
	Accessible vehicles			■					Yes

4.1.4 UNECE regulations only (TP3)

Cost effectiveness and casualty impact

Table 16: Summary of key results (TP3, Central Estimate)

	KSIs prevented 2025–2039	Fitment costs (£ million)	EANDCB (£ million)	BCR
M1	4,407	524.3	44.2	4.4
M2M3	627	9.1	0.2	29.9
N1	383	75.4	5.3	2.9
N2N3	495	97.1	4.1	3.5
Total	**5,667**	**710.6**	**53.7**	**4.4**

Note that the total impacts cannot be derived by summing up the individual vehicle category results (see Section 3.3).

In this package (TP3), technologies were only included if they were already regulated at UNECE level. Fourteen technologies were included: BSI, DIV, EBC, EBP, EBV, EDR, ESS, FFI, FOI, MOI, PSI, PWI, RMA, and TPM. Table 16 shows that a comparatively small number of KSIs would be prevented with this approach compared to TP1 – approximately 5,600, of which the vast majority (approximately 4,400) would be casualties involving cars (M1). The fitment costs are over £700 million and the total BCR is still very high at 4.4 with all vehicle categories comfortably exceeding 2 (high). The annual costs to business are about £54 million which is much less than for TP1.

Secondary impacts

The secondary impacts identified for TP3 are summarised in Table 17.

Table 17: Summary of secondary impacts (TP3), their qualitative appraisals on seven-point scale (strongly adverse to strongly beneficial) and potential relevance for Public Sector Equality Duty (PSED)

Impacts		–3	–2	–1	0	+1	+2	+3	PSED relevant
Economic	Journey time reliability					■			No
	Technological capabilities					■			No
	Resources for research						■		No
Environmental	Traffic noise					■			No
	Water pollution					■			No
Social	Journey time reliability					■			No
	Active travel					■			No
	Crime				■				No
	Access to justice						■		No
	Affordability		■						Yes
	Accessible vehicles			■					Yes

4.1.5 Regulation based on pessimistic cost effectiveness (TP4)

Cost effectiveness and casualty impact

Table 18: Summary of key results (TP4, Central Estimate)

	KSIs prevented 2025–2039	Fitment costs (£ million)	EANDCB (£ million)	BCR
M1	5,637	562.2	47.3	5.5
M2M3	747	11.2	1.0	32.1
N1	384	75.4	6.5	3.0
N2N3	1,132	99.3	8.5	7.1
Total	**7,460**	**751.0**	**63.3**	**5.6**

Note that the total impacts cannot be derived by summing up the individual vehicle category results (see Section 3.3).

In package TP4, only technologies which were found to be cost-effective (BCR > 1) even in the Pessimistic scenario (low casualties, low technology effectiveness, high costs) are bundled together. Eight technologies are included in this package: ADW, AIF, DAW, EBP, EBV, EDR, ELK and MOI.

As Table 18 shows, a comparatively low number of KSIs are prevented – just under 7,500, but the total BCR is nevertheless very high at 5.6. The fitment costs amount to just over £750 million over the 15-year appraisal period, while the EANDCB is in the middle of the range for the packages at almost £63 million.

Secondary impacts

The secondary impacts identified for TP4 are summarised in Table 19.

Table 19: Summary of secondary impacts (TP4), their qualitative appraisals on seven-point scale (strongly adverse to strongly beneficial) and potential relevance for Public Sector Equality Duty (PSED)

Impacts		–3	–2	–1	0	+1	+2	+3	PSED relevant
Economic	Journey time reliability					■			No
	Technological capabilities					■			No
	Resources for research						■		No
Environmental	Traffic noise				■				No
	Water pollution				■				No
Social	Journey time reliability					■			No
	Active travel					■			No
	Crime					■			No
	Access to justice						■		No
	Affordability			■					Yes
	Accessible vehicles			■					Yes

4.1.6 Regulation based on pessimistic casualty effectiveness (TP5)

Cost effectiveness and casualty impact

Table 20: Summary of key results (TP5, Central Estimate)

	KSIs prevented 2025–2039	Fitment costs (£ million)	EANDCB (£ million)	BCR
M1	9,846	932.6	71.0	5.1
M2M3	1,706	15.6	1.4	49.8
N1	858	126.6	7.3	3.7
N2N3	2,700	138.2	12.4	10.9
Total	**13,943**	**1,217.1**	**92.1**	**5.7**

Note that the total impacts cannot be derived by summing up the individual vehicle category results (see Section 3.3).

As for TP4, the selection of technologies for this package (TP5) was based on their impact in the Pessimistic scenario: Only technologies which are expected to prevent ≥ 100 KSIs even in the assumed worst scenario are included. TP5 includes eleven technologies: ADW, DAW, EBC, EBP, EBV, EDR, ELK, FFI, ISA, MOI and RMA.

The number of KSIs prevented is very high and reaches almost the same level as TP1 while the total BCR even exceeds TP1 at 5.7 (very high). The costs of fitment and annual costs to business are lower than TP1 at £1.2 billion and £92 million, respectively.

Secondary impacts

The secondary impacts identified for TP5 are summarised in Table 21.

Table 21: Summary of secondary impacts (TP5), their qualitative appraisals on seven-point scale (strongly adverse to strongly beneficial) and potential relevance for Public Sector Equality Duty (PSED)

Impacts		–3	–2	–1	0	+1	+2	+3	PSED relevant
Economic	Journey time reliability						■		No
	Technological capabilities					■			No
	Resources for research						■		No
Environmental	Traffic noise					■			No
	Water pollution				■				No
Social	Journey time reliability						■		No
	Active travel						■		No
	Crime				■				No
	Access to justice						■		No
	Affordability		■						Yes
	Accessible vehicles			■					Yes

4.1.7 Vulnerable road user protection (TP6)

Cost effectiveness and casualty impact

Table 22: Summary of key results (TP6, Central Estimate)

	KSIs prevented 2025–2039	Fitment costs (£ million)	EANDCB (£ million)	BCR
M1	5,681	593.9	42.5	4.0
M2M3	1,688	17.5	1.6	43.6
N1	599	81.3	3.5	3.7
N2N3	2,692	171.1	15.3	8.8
Total	**9,741**	**869.1**	**62.9**	**5.2**

Note that the total impacts cannot be derived by summing up the individual vehicle category results (see Section 3.3).

This package (TP6) is aimed at protecting pedestrians and cyclists by actively preventing collisions and mitigating those remaining. As a result, the package only includes active (primary) and passive (secondary) safety technologies with a high potential for protecting VRUs. TP6 comprises the following ten technologies: ADW, BSI, DAW, DIV, EBC, EBP, ISA, MOI, PWI, and RMA.

The total BCR is very high at 5.2 with lower fitment costs, but the number of KSIs prevented (approximately 9,700) is lower compared to TP1 and TP5. At £63 million, the EANDCB is about two thirds that of TP1.

Secondary impacts

The secondary impacts identified for TP6 are summarised in Table 23.

Table 23: Summary of secondary impacts (TP6), their qualitative appraisals on seven-point scale (strongly adverse to strongly beneficial) and potential relevance for Public Sector Equality Duty (PSED)

Impacts		–3	–2	–1	0	+1	+2	+3	PSED relevant
Economic	Journey time reliability					■			No
	Technological capabilities					■			No
	Resources for research				■				No
Environmental	Traffic noise					■			No
	Water pollution				■				No
Social	Journey time reliability					■			No
	Active travel						■		No
	Crime				■				No
	Access to justice				■				No
	Affordability			■					Yes
	Accessible vehicles			■					Yes

4.1.8 *Vehicle manipulation technologies (TP7)*

Cost effectiveness and casualty impact

Table 24: Summary of key results (TP7, Central Estimate)

	KSIs prevented 2025–2039	Fitment costs (£ million)	EANDCB (£ million)	BCR
M1	4,998	502.7	42.3	5.5
M2M3	0	0.0	0.0	0.0
N1	329	67.1	5.8	2.8
N2N3	0	0.0	0.0	0.0
Total	**5,141**	**569.8**	**48.1**	**5.0**

Note that the total impacts cannot be derived by summing up the individual vehicle category results (see Section 3.3).

TP7 was the smallest technology package analysed, comprising only four technologies: EBC, EBP, EBV, and ELK. These are active (primary) safety technologies that interact with driver control.

This package prevents a relatively small number of KSIs – just over 5,100. The fitment costs are below £570 million due to only four technologies being included, and as a result the total BCR is also very high at 5.0. The EANDBC is the lowest of all the packages at £48 million, just under half that of TP1.

Secondary impacts

The secondary impacts identified for TP7 are summarised in Table 25.

Table 25: Summary of secondary impacts (TP7), their qualitative appraisals on seven-point scale (strongly adverse to strongly beneficial) and potential relevance for Public Sector Equality Duty (PSED)

Impacts		−3	−2	−1	0	+1	+2	+3	PSED relevant
Economic	Journey time reliability					■			No
	Technological capabilities					■			No
	Resources for research				■				No
Environmental	Traffic noise				■				No
	Water pollution				■				No
Social	Journey time reliability					■			No
	Active travel					■			No
	Crime				■				No
	Access to justice				■				No
	Affordability			■					Yes
	Accessible vehicles			■					Yes

4.2 Individual technologies

All nineteen technologies have been analysed for their impacts, were they to be mandated individually. These results can be used to understand the scale of each technology's contribution to the impact of packages.

Table 26 presents the key results for this purpose, which are BCR, KSIs prevented and technology fitment costs. Note that the impacts of individual technologies cannot be simply summed up to derive the impacts of technology packages because CIAM considers overlaps in the casualty target populations and costs in order to avoid overestimating impacts. Overestimates would otherwise arise from double-counting avoided collisions that could be addressed by more than one technology, such as a front-to-rear shunt collision (target population for EBV) that was contributed to by speeding (target population for ISA), or from double-counting costs for sensors which can serve more than one technology and therefore share costs, such as windscreen-mounted cameras or radars.

Table 26: Summary of key results for individual technologies: Killed and seriously injured (KSI) casualties prevented, benefit-cost ratios (BCRs), technology fitment costs, and repair and maintenance costs

	KSIs prevented 2025–2039	BCR	Fitment costs (£ million)	Repair / maintenance costs (£ million)	Comments
ADW	908	3.2	187.7	0.0	–
AIF	157	11.7	6.7	0.0	–
BSI	135	2.5	23.7	2.1	Not applicable for M1 or N1
DAW	784	23.6	17.2	0.0	–
DIV	29	0.7	21.3	0.0	Not applicable for M1 or N1 Technology implementation dates: 2026/29 for M2M3, N2N3
EBC	517	1.4	141.9	12.5	Not applicable for M2M3 or N2N3
EBP	1,021	2.7	142.5	13.1	Not applicable for M2M3 or N2N3
EBV	1,937	7.9	170.0	17.4	Not applicable for M2M3 or N2N3
EDR	426	6.7	27.7	0.0	Technology implementation dates: 2026/29 for M2M3, N2N3
ELK	1,680	2.1	359.6	38.6	Not applicable for M2M3 or N2N3
ESS	11	1.4	6.7	0.0	–
FFI	444	2.1	55.4	0.0	Not applicable for M2M3 or N2N3
FOI	49	2.3	5.7	0.0	Not applicable for M1, M2M3 or N2N3
ISA	5,505	6.6	333.1	91.6	–
MOI	635	11.6	26.2	2.3	Not applicable for M1 or N1
PSI	81	0.6	48.2	0.0	Not applicable for M2M3 or N2N3
PWI	23	0.3	23.5	0.0	Not applicable for M2M3 or N2N3
RMA	337	1.3	125.4	13.1	–
TPM	3	11.1	14.9	0.0	Not applicable for M1

For individual technologies there is a clear lead in terms of KSIs prevented: ISA, which could prevent over 5,500 KSIs over the 15-year appraisal period. Other technologies which could avoid over 1,000 KSIs are (in descending order of impact): EBV, ELK and EBP. Six technologies are estimated to avoid fewer than 100 KSIs: DIV, ESS, FOI, PSI, PWI and TPM, in part due to their not being implemented for all vehicle categories and a later implementation date (DIV).

Due to its relatively high costs, ISA does not generate the highest BCR (at 6.6), that being DAW (with a BCR of 23.6), although there being a number of other technologies with very high BCRs: AIF, EBV, EDR, MOI and TPM. Three technologies generate poor BCRs of less than one: DIV, PSI and PWI.

The highest technology fitment cost would be from the introduction of ELK (£360 million), although the cost of ISA would be at a similar level (£333 million). These two technologies are the costliest, almost double that of the next highest – ADW at £188 million. Other technologies with fitment costs exceeding £100 million are: EBC, EBP, EBV and RMA.

Figure 5 presents a visual overview of the cost effectiveness and casualty impact of each individual technology.

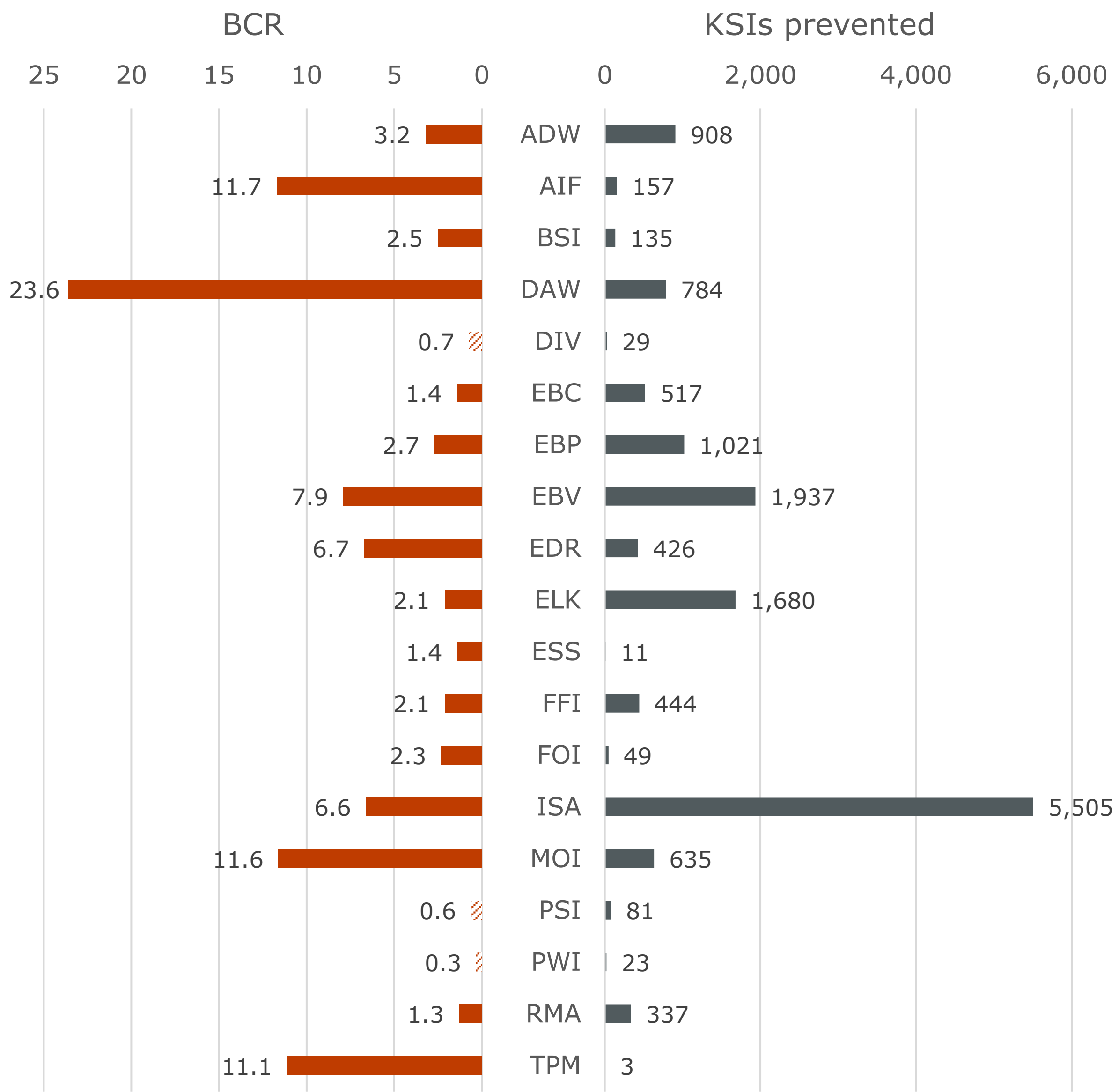


Figure 5: Summary overview of benefit-cost ratios (BCRs) and killed and seriously injured (KSI) casualties prevented by technologies when mandated individually; hatched orange bars indicating BCR < 1 (DIV, PSI, PWI)

5 Conclusions

The primary objective of the vehicle technologies considered for implementation is to reduce road collisions and casualties, but two technologies, intelligent speed assistance (ISA) and tyre pressure monitoring (TPM), would also have environmental and traffic benefits, all of which were quantified in this CBA. The results reported describe the difference between an intervention (mandatory implementation of technologies) and the business-as-usual case (continued voluntary adoption in a market environment where technologies are mandatory in the EU). Three factors are likely central to the selection process between technology packages, should intervention be sought: the BCR, the number of KSIs prevented, and the costs to business.

All seven technology packages have BCRs of 4.3 or higher, i.e. provide very high value for money, and take advantage of synergies between different technologies, such as lower costs due to sensor sharing, when implemented jointly.

Two packages stand out with a very high level of casualty benefits (see Figure 4, Page 27) – TP5 and TP1 both bring casualty benefits in the region of 14,000 KSIs prevented over the 15-year appraisal period. Understandably, the best performing technology package in terms of number of KSIs prevented is that which includes every single technology (TP1) at 14,406. In the final year of the appraisal period TP1 prevents the equivalent of 6.7% of the KSI casualties expected to be reported in GB in absence of the technologies. This is very closely followed by TP5 (regulation based on pessimistic casualty effectiveness), which includes only 11 of the 19 technologies and prevents only 463 fewer KSIs (ca. 3% fewer). Both packages are among the ones providing the highest value for money, with TP5 being the most cost effective in the field, at a BCR of 5.7 compared to 5.4 for TP1. Both packages, however, also create the highest cost to business in the field with EANDCBs at £98.2 million (TP1) and £92.1 million (TP5).

Two further packages, TP4 (regulation based on pessimistic cost effectiveness) and TP6 (vulnerable road user protection), are similar to TP1 and TP5 in terms of value for money but create lower cost to business with EANDCBs in the region of £63 million. The casualty benefits are in the middle of the range with KSIs prevented at 7,460 (TP4) and 9,741 (TP6).

Each of the remaining three packages, TP2 (all technologies excluding ISA), TP3 (UNECE regulations only) and TP7 (vehicle manipulation technologies), suffers from comparative shortcomings in at least one of the dimensions considered: TP2 provides the lowest value for money in the field (BCR: 4.3); TP3 and TP7 create low casualty benefits with KSIs prevented at 5,667 and 5,141 respectively. TP3 is unique in that it is entirely based on internationally harmonised regulations and would therefore, in practice, likely allow the quickest implementation in law because no domestic technical regulations would have to be developed.

Secondary economic, social and environmental impacts were also considered and appraised qualitatively. The analysis found that most secondary impacts lean in a beneficial direction with TP1 creating slight or moderate beneficial effects with regard to journey time reliability, technological capabilities, resources for research, traffic noise, water pollution, active travel, crime and access to justice. TP5 offers similar benefits, except it has no effect on water pollution because tyre pressure monitoring (TPM) is not part of the package and thus the amount of tyre particulates released into the environment is not reduced, and no impact on crime because alcohol interlock facilitation (AIF) is not included. TP6 and TP7 were found to create fewer secondary impacts overall (no effects on resources for research, water pollution, crime or access to justice) and weaker beneficial effects on journey time reliability. Further, TP6 has a weaker beneficial effect on active travel, and TP7 has no effect on traffic noise. TP2 and TP3 have weaker beneficial effects than TP1 on journey time reliability and active travel, and TP3 has no effect on crime because AIF is not included. Potential adverse impacts identified regarded affordability and accessible vehicles, with TP1, TP2, TP3 and TP5 potentially having slight or moderate adverse effects. For TP6 and TP7, the adverse impact on affordability is weaker. Both effects should also be considered in the context of the Public Sector Equality Duty's protected characteristics 'age' and 'disability', because affordability might affect different age groups differently and because many motorised road users with disabilities require substantial alterations to their vehicles which may involve adapting or disabling some of the vehicle technologies considered. For potential implementing legislation, it should be investigated whether targeted exemptions are required to ensure that the manufacture of accessible vehicles is not hindered.

Overall, this study concluded that TP1 (all technologies) and TP5 (regulation based on pessimistic casualty effectiveness) will offer very high value for money, create mostly beneficial secondary economic, social and environmental impacts and prevent in the region of 14,000 KSI casualties over the 15-year appraisal period compared to business as usual. TP3 (UNECE regulations only) would, in practice, likely be quicker to implement in law than other packages but it offers somewhat lower value for money and prevents considerably fewer casualties (ca. 5,700 KSIs). A staged approach to implementation could be considered, where technologies based on UNECE regulations are implemented first to realise some benefits as early as possible, and other technologies follow later once domestic technical regulations have been developed.

6 Acknowledgements

TRL would like to acknowledge the stakeholders who supported us in this study. We thank you for your time and effort and your valuable contributions.

We also thank the peer reviewers for this study, Dr Huw Davies and Dr Christophe Bastien, Centre for Future Transport and Cities, Coventry University, for their insightful comments.

7 References

20's Plenty for Us. (2023, March 27). *20MPH LIMITS ENCOURAGE WALKING AND CYCLING*. Retrieved from 20MPH LIMITS ENCOURAGE WALKING AND CYCLING: https://www.20splenty.org/20mph_limits_encourage_walking_and_cycling

ACEA. (2017). *Reverse detection for N2/N3/O Accident Analysis.* unpublished.

Air Quality Expert Group. (2019). *Non-Exhaust Emissions from Road Traffic.* Department for Environment, Food and Rural Affairs (Defra).

American Automobile Association, Inc. (2018, October). Fact Sheet: Advanced driver assistance systems (ADAS) repair costs.

Autovista24. (2018). Uptake in vehicle safety systems sees UK road accidents drop. *Autovista24*, 1.

Barrow, A., Edwards, A., Smith, L., Khatry, R., Kalaiyarasan, A., & Hynd, D. (2017). *Effectiveness estimates for proposed amendments to the EU's General and Pedestrian Safety Regulations - PPR844.* Crowthorne: TRL.

Billot, O., Coulot, M., Zeitouni, R., Adalian, C., & Chauvel, C. (2013). Pole impact test: Study of the two current candidates in terms of cost and benefits in France. *ESV Conference Proceedings.* Washington: NHTSA.

Blackmore, K. (2018). Driver assistance technology is helping drive down the number of accidents on our roads. *Fleet Alliance*, 1.

BOVAG. (2019). Het effect van ADAS op schadeherstel, onderhound en reparatie.

Broughton, J. (1991). Forecasting road accident casualties in Great Britain. *Accident Analysis & Prevention, 23*(5), 353-362. doi:https://doi.org/10.1016/0001-4575(91)90056-B

Broughton, J. (2011). *Updated post-2010 casualty forecasts. TRL Published Project Report PPR552 https://trl.co.uk/publications/ppr552.* Wokingham: TRL. Retrieved from TRL.

Carsten O, F. M. (2008). *Intelligent Speed Adaptation - UK Final Report.* DfT.

Carsten O, L. F. (2008). *Speed Limit Adherence and its Effect on Road Safety and Climate Change.* Institure for Transport Studies.

Chajmowicz H, S. J. (2019). Prospective assessment of the effectiveness of autonomous emergency braking in car-to-cyclist accidents in France. *Traffic Injury Prevention*, S20-S25.

Cicchino, J. (2017). Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates. *Accident Analysis & Prevention*.

Cicchino, J. (2018). Effects of lane departure warning on police-reported crash rates. *Journal of Safety Research*.

Cicchino, J. (2022). Effects of automatic emergency braking systems on pedestrian crash risk. *Accident Analysis & Prevention*, Volume 172.

Cicchino, J. (2022). Effects of automatic emergency braking systems on pedestrian crash risk. *Accident Analysis and Prevention*.

Cicchino, J. (2023). Effects of a bicyclist detection system on police-reported bicycle crashes. *Proceedings of the 27th ESV Conference.* Yokohama: NHTSA.

Department for Transport. (2015). *Value for Money Framework.* London: DfT. Retrieved from https://assets.publishing.service.gov.uk/media/5f6237408fa8f5106d15640c/value-for-money-framework.pdf

Department for Transport. (2022). *National Road Traffic Projections 2022.* London: Department for Transport. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1123542/national-road-traffic-projections-2022.pdf

Department for Transport. (2023). Retrieved 2023, from Guidance - TAG data book: https://www.gov.uk/government/publications/tag-data-book

Department for Transport. (2023). *Statistical data set - Road traffic statistics (TRA)*. Retrieved from https://www.gov.uk/government/statistical-data-sets/road-traffic-statistics-tra

DfT. (2021). *Other Sources of information on road casualties*. Retrieved from Gov.uk: https://www.gov.uk/government/publications/other-sources-of-information-on-road-casualties/other-sources-of-information-on-road-casualties

DfT. (2023). Traffic volume in kilometres (TRA0102). Retrieved 2023, from https://www.gov.uk/government/statistical-data-sets/road-traffic-statistics-tra

DfT. (n.d.). *A valuation of road accidents and casualties in Great*. Retrieved 2023, from Gov.uk: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/995110/rrcgb-valuation-methodology.pdf

DfT. (n.d.). *RAS4201: National Travel Survey self-reported injuries in road collisions*. Retrieved from Gov.uk: https://www.gov.uk/government/statistical-data-sets/reported-road-accidents-vehicles-and-casualties-tables-for-great-britain#other-road-safety-data-ras40

Dodd, M. (2022). *Analysis of the effectiveness of retrofit ISA on TfL's fleet vehicles.* London: TfL.

Doecke, S. D., Raftery, S. J., Elsegood, M. E., & Mackenzie, J. R. (2021). *Intelligent Speed Adaptation (ISA): benefit analysis.* Adelaide: Centre for Automotive Safety Research.

Edwards, M., Wisch, M., Pastor, C., Price, J., Broughton, J., & Adolph, T. (2013). *FIMCAR XIII - Cost Benefit Analysis.* Berlin: TU Berlin.

Egaji O A, C. S. (2019). An innovative decision rule approach to tyre pressure monitoring. *Expert Systems with Applications*, (pp. 252-270).

Ellis, C., Hammond, J., Kent, J., & Appleby, J. (2018). *DRIVEN Deliverable D6.3 - Creating the route risk tool.* Crowthorne: TRL.

Elvik, R., & Hoye, A. (2022). Do we know why the number of traffic fatalities is declining? If not, can we find out? *Traffic Safety Research, 2*. doi:https://doi.org/10.55329/oyhu8693

Elvik, R., & Høye, A. K. (2020). *The potential for reducing the number of killed or seriously injured road users in Norway in the period 2018-2010.* Oslo: Institute of Transport Economics.

Elvik, R., & Vaa, T. (2004). *The Handbook of Road Safety Measures.* Oslo: Pergamon.

Euro NCAP. (2011). *Reward 2011 - Ford Driver Alert.* Euro NCAP.

European Commission. (2020). *EU road safety policy framework 2021-2030 – Next steps towards 'Vision Zero' Commission Staff Working Document SWD(2019) 283 final.* Brussels: European Commission.

Farmer, C. (2005). Relationships of Frontal Offset Crash Test Results to Real-World Driver Fatality Rates. *Traffic Injury Prevention*.

Folgero, I. K., Harding, T., & Benjamin, W. S. (2020). *Going fast or going green? Evidence from environmental speed limits in Norway.* Bergen: NHH Norwegian School of Economics.

Glasgow, U. o. (n.d.). How Automated Decision-Making can Increase the Safety of Connected and Autonomous Vehicles. *IP & Commercialisation Unit*, 11.

Gressai, M., Varga, B., Tettamanti, T., & Varga, I. (2021). *Investigating the impacts of urban speed limit reduction through microscopic traffic simulation.* Budapest: Budapest University of Technology and Economics.

Haus S, S. R. (2019). Estimated benefit of automated emergency braking systems for vehicle–pedestrian crashes in the United States. *Traffic Injury Prevention*, S171 - S176.

iRAP. (2013). iRAP methodology factsheet 12 Multiple countermeasures. Retrieved 2023, from https://irap.org/methodology/

Jackson, P., Hilditch, C., Holmes, A., Reed, N., Merat, N., & Smith, L. (2011). *Road Safety Web Publication No. 21 Fatigue and Road Safety: A Critical Analysis of Recent Evidence.* London: Department for Transport.

Jamson S, C. O. (2006). *Intelligent Speed Adaptation Literature Review and Scoping Study.* University of Leeds, MIRA Ltd and TfL.

Keall, M., Fildes, B., & Newstead, S. (2017). Real-world evaluation of the effectiveness of reversing camera and parking sensor technologies in preventing backover pedestrian injuries. *Accident Analysis and Prevention*.

Kole P J, L. A. (2017). *Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment.* Int. J. Environ. Res. Public Health.

Kovaceva J, B. A. (2020). Safety benefit assessment of autonomous emergency braking and steering systems for the protection of cyclists and pedestrians based on a combination of computer simulation and real-world test results. *Accident Analsis & Prevention*, Volume 136.

Kullgren, A., Amin, K., & Tingvall, C. (2023). Effects on crash risk of automatic emergency braking systems for pedestrians and bicyclists. *Proceedings of the 27th ESV conference.* Yokohama: NHTSA.

Lai, F., Carsten, O., & Tate, F. (2012). How much benefit does Intelligent Speed Adaptation deliver: An analysis of its potential contribution to safety and environment. *Accident Analysis and Prevention*.

Laxton V, O. E. (2022). *Technical support to assess the upgrades necessary to the advanced driver distraction warning systems.*

Leslie A, K. R. (2021). Field effectiveness of general motors advanced driver assistance and headlighting systems. *Accident Analysis & Prevention*, Volume 159.

Martino, A., Sitran, A., & Rosa, C. (2014). *Technical development and deployment of alcohol interlocks in road safety policy.* Brussels: European Parliament.

Marton Z, F. D. (2014). Frequency analysis based Tire Pressure Monitoring.

McDonald, C. (2022). On the Road to ADAS Data. *Actuarial Post*, 1.

National Heart Forum. (2010). Reducing the default speed limit in built-up areas: Highlighting the health benefits of 20mph. 10.

nonoise.org. (2023, March 23). *Noise Increases with Vehicle Speed*. Retrieved from https://www.nonoise.org/resource/trans/highway/spnoise.htm

Ntziachristos, L., & Boulter, P. (2019). *EMEP/EEA air pollutant emission inventory guidebook 2019 - 1.A.3.b.vi-vii Road tyre and brake wear 2019.* EMEP/EEA. Retrieved from https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-vi/view

Paine, M. (2009). *Low Range Speeding and the Potential Benefits of Intelligent Speed Assistance.* Sydney: Australasian Road Safety Research.

Papageorgiou, M., Papamichail, I., & Kosmatopoulos, E. (2008). *Effects of Variable Speed Limits on Motorway Traffic Flow.* Transportation Research Record Journal of the Transportation Research Board.

Pölös, Z. (2022). *trans.info*. Retrieved 2023, from https://trans.info/underinflated-tyres-check-293869

RoadSafe. (2022). Majority of motorists back ISA. *Road Safe*, 1.

Ryan, M. (2019). Intelligent speed assistance technologies: A review. *ITRN.*

Seidl M, H. D. (2017). *In depth cost-effectiveness analysis of the identified measures and features regarding the way forward for EU vehicle safety.* European Commission.

Sexton, B., & Johnson, B. (2009). *An evaluation of options for road safety beyond 2010. PPR397.* Wokingham: TRL.

Simpson, H. F., & O'Reilly, D. M. (1994). *Revaluation of the accident related costs of road accidents, TRL Project Report 56.* TRL.

SMMT. (2019). *2019 UK Automotive Sustainability Report.* London. Retrieved from https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-Sustainability-Report-2019.pdf

Soriguera, F., Martinez, I., Sala, M., & Menendez, M. (2017). *Effects of low speed limits on freeway traffic flow.* Barcelona, Zürich: Elsevier Ltd.

Sternlund, S., Strandroth, J., Rizzi, M., Lie, A., & Tingvall, C. (2017). The effectiveness of lane departure warning systems—A reduction in real-world passenger car injury crashes. *Traffic Injury Prevention*.

Szczucka-lasota B, K. J. (2019). Influence of tire pressure on fuel consumption in trucks with installed tire pressure monitoring systems (TPMS). *Scientific Journal of Silesian University of Technology*, 167-181.

TfL. (2022). *Westminster - Introducing lower speed limits.* london: TfL.

Thatcham Research. (2017, June 6). *Thatcham Research calls for new thinking and approaches to halt spiralling cost of repair*. Retrieved from news.thatcham.org: https://news.thatcham.org/pressreleases/repair-focus-2017-thatcham-research-calls-for-new-thinking-and-approaches-to-halt-spiralling-cost-of-repair-2002192

Thomas J, H. S. (2014). Fuel Economy and Emissions Effects of Low Tire Pressure, Open Windows, Roof Top and Hitch-Mounted Cargo, and Trailer. *SAE International*.

Toma, M. A. (2018). Influence of tire inflation pressure on the results of diagnosing brakes and suspension. *Procedia Manufacturing*, 121-128.

Unger T, S. A. (2018). *Qualitative assessemnt of Intelligent Speed Adaptation (ISA) systems.* VUFO GmbH. Technische Universitat Dresden.

US EPA & NHTSA. (2016). *Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heay-Duty Engines and Vehicles - Phase 2.*

Volvo Trucks. (2020). *Tyres and how they impact fuel consumption.* Gothenburg: Volvo Trucks.

webuyanycar. (2023, March 27). *In a dash*. Retrieved from webuyanycar.com: https://www.webuyanycar.com/about-us/press-centre/in-a-dash/

Wright, C. (2022). Collision avoidance is top ADAS system for fleets. *Business Motoring*, 1.

Appendix A Vehicle technologies – technical information

This appendix provides for each of the vehicle technologies a summary table of the relevant technical requirements. Some of the technical requirements were not well defined at the time of the EU cost-benefit analysis (Seidl M, 2017). The tables therefore highlight important technical differences between the EU assumptions and the final implementations which were taken into account for the decision to what extent EU input values on costs or effectiveness need to be revised for the present study.

A.1 Overview of regulatory technical requirements

A.1.1 Advanced distraction warning

Advanced distraction warning	
Technology code	ADW
Description	Driver assistance technology that alerts the driver when visual distraction is detected.
Regulation	Commission Delegated Regulation (EU) on ADDW (regulation not yet published; latest draft requirements specified in document C(2023) 4523 Final)
Vehicle categories	M_1, N_1, M_2 & M_3, N_2 & N_3
Implementation years	2025 / 2027
Technical requirements	*Note that the technical requirements for ADW in European Regulation have not been finalised yet, but an advanced draft of the regulation is available (V3.2 for regulation and V4.2 for technical annexes), on which the following information is based.* ADW detects when the driver's visual attention is not directed towards the driving task and alerts the driver. To detect distraction, the system monitors the driver's gaze direction. The regulation defines a distracted zone (approximately looking down 30 degrees and excluding the glazed area) and defines distraction when the driver's gaze is directed in that zone for 3.5 s (at driving speeds greater than 50 km/h) or 6 s (speeds greater than 20 km/h). When distraction is detected, ADW alerts the driver with visual signal and one further means out of acoustic or haptic. ADW is active for vehicle speeds greater than 20 km/h and operates effectively during day- and night-time conditions. ADW is default-on at vehicle start and the warnings can be deactivated by the driver; it is automatically re-instated for the next journey. Approval of the system is based on a review of technical documentation submitted by the manufacturer and testing by the technical service. Before application, the manufacturer validates the system in trials with human participants in a driving simulator or on a test track or open road. The technical service performs spot check testing of some of the reported results in a test track setting or driving simulator with test drivers.
Differences to EU cost-benefit assumptions	The EU assessment assumed a system that detects drowsiness as well as long lasting and short-term inattention/distraction. The technical specification is limited to long-lasting and short-term distraction which reduces the target population and potentially cost.

A.1.2 Alcohol interlock facilitation

Alcohol interlock facilitation	
Technology code	AIF
Description	Facilitation of the installation of an alcohol interlock, a driver assistance technology that prevents persons with alcohol concentrations in their bodies exceeding a set limit value from starting a motor vehicle.
Regulation	Commission Delegated Regulation (EU) 2021/1243
Vehicle categories	M_1, N_1, M_2 & M_3, N_2 & N_3
Implementation years	2025 / 2027
Technical requirements	AIF ensures that vehicles can be fitted with an alcohol interlock complying with European Standards EN 50436-1:2014 or EN 50436-2:2014+A1:2015. Manufacturers have to make installation facilitation information, in the form of a standardised installation document (EN 50436-7:2016), accessible in accordance with Annex X of Regulation (EU) 2018/858. The regulation further specifies some technical aspects relating to the alcohol interlock, if installed, including that it shall be in the blocking state normally and only un-block after an acceptable breath sample, and that it only intervenes in the starting process of a vehicle but not influence a running engine or moving vehicle.
Differences to EU cost-benefit assumptions	None

A.1.3 Blind spot information

Blind spot information	
Technology code	BSI
Description	Primary safety technology that informs the driver when a cyclist is close to the nearside of the vehicle and warns the driver when a turning collision on the nearside becomes more likely.
Regulation	UN Regulation No. 151, Original Version
Vehicle categories	M_2 & M_3, N_2 & N_3
Implementation years	2025 / 2027
Technical requirements	BSI visually informs the driver about nearby cyclists that might be endangered during a potential turn to the nearside and also about cyclists approaching at speeds between 5 km/h and 20 km/h on the nearside while the vehicle is stationary. The system warns the driver by a visual, acoustic or haptic signal when the risk of a collision increases, e.g. due to the intention of a turn towards the cyclist. BSI is active for vehicle speeds between 0 km/h and 30 km/h. It must operate in ambient light conditions down to 15 lux, i.e. also with relatively low light levels. BSI information and warning signals are default-on at vehicle start. The entire BSI or only the warning signal can be deactivated by the driver; they are automatically re-instated for the next journey. System performance is assessed in a series of dynamic and static tests with a bicycle dummy on a test track. Dummy and/or vehicle are moved, and the system information and warning behaviour is assessed for compliance based on geometric zones of proximity.
Differences to EU cost-benefit assumptions	The EU assessment assumed a system that reacts to pedestrians and cyclists on both sides of the vehicle. The technical specification is limited to cyclists and the vehicle's nearside which reduces the target population and potentially cost. Note that detection of vulnerable road users in front of the vehicle is considered under a separate technology (moving off information).

A.1.4 Drowsiness and attention warning

Drowsiness and attention warning	
Technology code	DAW
Description	Driver assistance technology that warns the driver when driver drowsiness is detected.
Regulation	Commission Delegated Regulation (EU) 2021/1341
Vehicle categories	M_1, N_1, M_2 & M_3, N_2 & N_3
Implementation years	2025 / 2027
Technical requirements	DAW provides a visual, acoustic or other warning to the driver when drowsiness equivalent to level 8 or above on the reference sleepiness scale (Karolinska Sleepiness Scale) is detected. DAW is active for vehicle speeds above 70 km/h. Vehicles with a maximum design speed of 70 km/h or less are exempt from the scope of the regulation. To detect drowsiness, the system analyses the driving patterns, such as the driver's steering pattern or variability in lateral lane position. The regulation is not prescriptive as to the sensing technology used and may also include physiological metrics. DAW is default-on at vehicle start and the warnings can be manually deactivated by the driver; it is automatically re-instated for the next journey. System performance is validated during day- and night-time conditions in real-world driving or driving simulator tests involving at least 10 human participants. The validation tests are carried out by the manufacturer and a documentation package is submitted to the technical service for approval. As part of the documentation assessment, the technical service also performs the test based on the reported manufacturer protocol and is passed if the system provides a warning.
Differences to EU cost-benefit assumptions	The EU assessment assumed a system that detects drowsiness and long-lasting inattention/distraction. The technical specification is limited to drowsiness which reduces the target population and potentially cost.

A.1.5 Direct vision

Direct vision	
Technology code	DIV
Description	Design requirement which ensures that a minimum volume in proximity to the vehicle's front, nearside and offside can be observed by the driver in direct vision (i.e. without the aid of mirrors or cameras) to allow detection of pedestrians and cyclists.
Regulation	UN Regulation No. 167, Original Version
Vehicle categories	M_2 & M_3, N_2 & N_3
Implementation years	2026 / 2029
Technical requirements	DIV ensures that a certain minimum volume around the vehicle is visible in direct vision from a typical driver's seating position. The zone around the vehicle taken into account for the assessment extends 2.0 metres to the front, 4.5 metres to the nearside, 2.0 metres to the offside, 1 metre to the rear with a height extending from ground level to 1.6 metres. The required visible volume within this area depends on the vehicle category and technical criteria (e.g. axle configuration, cab type), which are indicative of how likely frequent urban use of the vehicle type is. The total visible volume required ranges from 7.0 m^3 (seldom urban use) to 11.2 m^3 (frequent urban use). The assessment of the visible volume can either be performed by a static physical test, using cameras positioned in the cab, and grid lines and area markers outside the vehicle, or by a numerical test using a CAD model of the vehicle.
Differences to EU cost-benefit assumptions	The EU assessment was based on best-in-class direct vision approach, i.e. the least challenging level of requirements investigated at the time (the other option investigated was a high-visibility cab). The best-in-class approach is the best match for the actual requirements implemented in UN R167; therefore no adaptation of the input values is required.

A.1.6 Emergency braking for vehicles, pedestrians, and cyclists

Emergency braking for vehicles, pedestrians, and cyclists	
Technology code	EBV, EBP, EBC
Description	Primary safety technology that warns the driver and automatically brakes when a frontal collision with a preceding car or with a pedestrian or cyclist crossing the road is imminent
Regulation	UN Regulation No. 152, Original Version (EBV, EBP) UN Regulation No. 152,02 Series of Amendments (EBC; note that cyclist capability was only added in this series of amendments)
Vehicle categories	M_1, N_1
Implementation years	2025 / 2027
Technical requirements	EBV/EBP/EBC automatically brakes the vehicle with a demand of at least 5.0 m/s^2 when an imminent collision with a preceding vehicle of category M_1 or with a pedestrian or cyclist crossing the road is detected. A warning to the driver is also given, either 0.8 seconds before the brake intervention (if this still allows enough time to avoid the collision) or ultimately together with the brake intervention. The driver is able to interrupt collision warnings and brake interventions (e.g. by kick-down or operating the direction indicator control). The system is active for host vehicle speeds between 10 km/h and 60 km/h (EBV) or 20 km/h and 60 km/h (EBP and EBC). In good conditions, when driving straight and depending on vehicle load conditions, the system must avoid collisions up to ca. 40 km/h relative speed. At higher speed differentials, the impact speed must be reduced, e.g. from 60 km/h to 35 km/h. EBV is default-on at vehicle start and can be manually deactivated by the driver; it is automatically re-instated for the next journey. System performance is assessed in track tests with additional audit/documentation elements. The track tests are performed at speeds up to 60 km/h, driving in a straight line, with both a stationary and a moving soft target representing a saloon passenger car or an actual vehicle of that description which is laterally well-aligned (EPV) or with moving soft targets representing a child pedestrian (EBP) and an adult cyclist (EBC) which move perpendicularly across the road at 5 km/h and 15 km/h, respectively. The audit/documentation elements shall ensure that false positive interventions are minimised in challenging scenarios (e.g. turning right in front of a waiting vehicle, approaching a bend with a pedestrian walking on the pavement).
Differences to EU cost-benefit assumptions	None

A.1.7 Event data recorder

Event data recorder	
Technology code	EDR
Description	Technology that records critical, crash-related parameters before and during a collision to support accident reconstruction and research.
Regulation	UN Regulation No. 160, 01 Series of Amendments & Commission Delegated Regulation (EU) 2022/545
Vehicle categories	M_1, N_1, M_2 & M_3, N_2 & N_3
Implementation years	2025 / 2027 (M_1, N_1), 2026/2029 (M_2 & M_3, N_2 & N_3)
Technical requirements	The technical requirements for EDR in M_1 and N_1 vehicles comprise of two regulations: • UN Regulation No. 160, specifying triggering conditions for recording, the data elements to be recorded and the data format, the number of memory slots to hold events, and survivability of the data sets in collisions. • An EU regulation (Document C(2022)395), specifying data security, data retrieval and additional data elements. EDR needs to trigger data recording when airbags or safety belt pre-tensioners deploy, the vehicle experiences collision-like deceleration levels or an external secondary safety system for VRU protection is deployed (e.g. pop-up bonnet). The system needs to accommodate records of at least three events, capturing 65 data elements concerning the host vehicle (type, variant, version and fitted active safety and accident avoidance systems), vehicle motion (speed, pre-crash and crash accelerations, delta-v, roll angle), driver inputs (brake, accelerator, steering), safety belt status, airbag and pre-tensioner deployments and interventions by active safety systems/ADAS. The data recorded by EDRs is anonymised, so do not contain direct identifiers such as full vehicle identification number or indirect identifiers such as location or time of an event. It shall be possible to retrieve the data after impacts of a severity level set by UN Regulation Nos. 94, 95 or 137. Data retrieval shall be possible via the vehicle's on-board diagnostics (OBD) port or via direct connection to the EDR. The vehicle manufacturer must provide at request of a type-approval authority information about how the data can be accessed, retrieved and interpreted to manufacturers or repairers of components, diagnostic tools or test equipment. Data security of EDR is assured by protection against manipulation in line with UN Regulation No. 155 (cybersecurity and cybersecurity management system). For M_2, M_3, N_2 and N_3, no final requirements exist yet, but the working group negotiations allow the assumption that similar requirements to those discussed above will be agreed. The main differences will concern the definitions of triggering conditions for recording (trigger in heavy vehicles will be less specific, e.g. record at heavy braking or each vehicle stop), the recording duration (which will be extended to allow for a potentially longer time period between collision and recording trigger), and the omittance of data recording of vehicle accelerations and delta-v.
Differences to EU cost-benefit assumptions	The EU assessment assumed a fitment requirement only for M_1 and N_1 vehicles and a technical specification mirroring the existing US standard, which required fewer data elements. Recording of additional data elements could increase the cost. Additional vehicle categories (M_2, M_3, N_2, N_3) would have to be equipped.

A.1.8 Emergency lane keeping

Emergency lane keeping	
Technology code	ELK
Description	Primary safety technology that warns the driver of unintended lane departures and corrects the vehicle's course to avoid crossing solid lane markings
Regulation	Commission Implementing Regulation (EU) 2021/646
Vehicle categories	M_1, N_1
Implementation years	2025 / 2027
Technical requirements	ELK comprises a lane departure warning function and a corrective directional control function, both for unintentional lane departures at moderate lateral departure speeds. The functions react in all lighting conditions to dashed and solid lane markings, but not to unmarked road edges. For the types of lane markings to react to, the regulation refers to the relevant annex of UN Regulation No. 130 (LDWS for heavy vehicles), which includes UK lane markings. The warning function Is active at vehicle speeds between 65 km/h and 130 km/h. When a dashed or solid lane marking is crossed by 0.3 metres (maximum), the driver is alerted by a warning of two means out of visual, acoustic and haptic or an acoustic or haptic warning with spatial indication about the direction of unintended drift. The corrective function is active at vehicle speeds between 70 km/h and 130 km/h and only reacts to solid lane markings. When approaching or crossing such lane marking, the function prevents departure by more than 0.3 metres by a corrective intervention in the vehicle's course by active steering or differential braking. The intervention is indicated by a visual signal and can be overridden with moderate steering effort. ELK is default-on at vehicle start and can be manually deactivated by the driver (this requires at least two deliberate actions); it is automatically re-instated for the next journey. Approval tests are carried out at a range of departure rates on a test track. The approval process also contains a safety audit for electronic control functions and assessment of a documentation package, for instance on the strategy to recognise driver intended manoeuvres.
Differences to EU cost-benefit assumptions	The EU assessment assumed fitment of a lane keeping system that only intervenes when the threat of a collision with a vehicle in the adjacent lane is detected or the vehicle would leave the carriageway. The specified system does not have threat detection and a warning-only function for dashed lane markings which could reduce the cost but increase the likelihood of drivers switching the system off. The system also does not detect unmarked road edges which makes it ineffective without lane markings.

A.1.9 Emergency stop signal

Emergency stop signal	
Technology code	ESS
Description	Primary safety technology that indicates high braking deceleration to other road users to the rear of the vehicle.
Regulation	UN Regulation No. 48, 07 Series of Amendments
Vehicle categories	M_1, N_1, M_2 & M_3, N_2 & N_3
Implementation years	2025 / 2027
Technical requirements	ESS is specified as the simultaneous flashing of all stop or direction indicator lamps at a high frequency (4 Hz). The signal is given by the host vehicle and also by towed trailers. The signal is activated automatically at driving speeds greater than 50 km/h if the service brake is being applied and the resulting vehicle deceleration reaches at least 6 m/s^2 (M_1, N_1) or 4 m/s^2 (M_2, M_3, N_2, N_3), or the antilock system is fully cycling.
Differences to EU cost-benefit assumptions	None

A.1.10 Frontal full-width impact

Frontal full-width impact	
Technology code	FFI
Description	Crash test to improve the secondary safety of front row occupants in frontal impacts engaging the entire width of the vehicle.
Regulation	UN Regulation No. 137, 02 Series of Amendments
Vehicle categories	M_1, N_1
Implementation years	2025 / 2027
Technical requirements	FFI is assessed in a 50 km/h frontal impact test against a full-width rigid barrier. By engaging the entire width of the vehicle, this test challenges mostly the capability of the occupant restraint systems (airbags, safety belts, pre-tensioners, load limiters) to reduce injury risk in this loading condition and ensures that restraint systems will protect a range of occupant statures. The test setup consists of a 50th percentile Hybrid III male in the driver's seat and a 5th percentile Hybrid III female anthropometric test device (ATD) in the front passenger position. The ATDs must meet performance criteria relating to head, neck, thorax and femur protection. The regulation contains prescriptions to protect occupants of electric vehicles from high voltage and electrolyte leakage.
Differences to EU cost-benefit assumptions	The EU assessment considered implementation of FFI as two separate measures, firstly as unaltered UN Regulation No. 137 and secondly on the basis of the same regulation but with different ATDs (THOR) and lower injury criteria thresholds to encourage adaptive restraints. The specification considered is equivalent to the first measure; therefore, no differences.

A.1.11 Frontal off-set impact

Frontal off-set impact	
Technology code	FOI
Description	Crash test to improve the secondary safety of drivers in frontal impacts with another vehicle engaging only part of the vehicle width.
Regulation	UN Regulation No. 94, 04 Series of Amendments
Vehicle categories	N_1
Implementation years	2025 / 2027
Technical requirements	FOI is assessed in a 56 km/h frontal impact with 40% overlap against a deformable barrier to represent another vehicle. By engaging less than half of the vehicle width, this test challenges mostly the vehicle's crash absorbing structures and occupant restraint systems to reduce injury risk in this configuration as well as the vehicle's structural integrity to keep doors closed and limit compartment intrusion. The test setup consists of a 50th percentile Hybrid III male ATD in the driver's seat. The ATD must meet performance criteria relating to head, neck, thorax, femur, tibia and knee protection. The regulation contains prescriptions to protect occupants of electric vehicles from high voltage and electrolyte leakage.
Differences to EU cost-benefit assumptions	Not included in EU assessment

A.1.12 Intelligent speed assistance

Intelligent speed assistance	
Technology code	ISA
Description	Driver assistance technology that warns the driver or slows the vehicle down when the speed limit is being exceeded
Regulation	Commission Delegated Regulation (EU) 2021/1958
Vehicle categories	M_1, N_1, M_2 & M_3, N_2 & N_3
Implementation years	2025 / 2027
Technical requirements	ISA consists of a speed limit information function (SLIF; displays the applicable speed limit to the driver) and either a speed limit warning function (SLWF; warns the driver when speed limit exceeded) or a speed control function (SCF; automatically reduces driving speed when speed limit exceeded). The SLWF is active for speeds over 20 km/h and provides visual and acoustic, visual and haptic, or haptic-only warnings. Where two warning modes are combined, the acoustic or haptic warning will come on only after the speed limit violation persisted for between 3 and 6 seconds. SCF is an alternative to SLWF (at the manufacturer's choice). It is also active for speeds over 20 km/h and limits the vehicle speed by reducing the vehicle's propulsion power and driveline torque; in case of M_1 and N_1 vehicles application of the service brakes is also allowed. The system can be overridden by the driver (e.g. by pressing the accelerator harder or deeper). ISA is default-on at vehicle start and can be manually deactivated by the driver; it is automatically re-instated for the next journey. The technical requirements are based around speed limits indicated by road signs, i.e. determination of speed limits that are only indicated by infrastructure design such as dual carriageway/street lighting or are only painted on the road is not required. This allows in principle to fulfil the requirements with camera-only technology without map assistance. The relevant road signs that need to be observed by the system are listed in catalogue of road signs, which forms an annex to the regulation and will be periodically updated. Road signs for GB are not contained in the regulation to date. The EU regulation requires functionality in all EU countries but provides alleviations for vehicles intended for local or regional operation (e.g. buses of Classes I and A). Determination of the applicable speed limit is based on camera observation of explicit speed limit signs (i.e. those showing a numerical value) and camera observation or map data for implicit speed limit signs (i.e. those showing no numerical value, e.g. the national speed limit sign). The capability to determine the correct speed limit is assessed in a track test (with additional technical documentation) and a 400 km real-world driving test where the system needs to determine correctly for at least 90% of the driven distance. Equivalent life cycle performance must be ensured for at least 14 years after date of vehicle manufacture; this includes map updates (if maps are used by the system) which need to be provided free of charge for 7 years. Other test procedures include test track assessments of the SLWF and SCF.
Differences to EU cost-benefit assumptions	The EU assessment assumed camera-only systems, i.e. without map support. The specified real-world reliability requirements may make map-based technology necessary which could add cost and increase effectiveness.

A.1.13 Moving off information

Moving off information	
Technology code	MOI
Description	Primary safety technology that informs the driver when a pedestrian or cyclist is in the blind spot area in front of the vehicle and warns the driver when a moving off or low-speed impact with the vehicle front becomes more likely.
Regulation	UN Regulation No. 159, Original Version
Vehicle categories	M_2 & M_3, N_2 & N_3
Implementation years	2025 / 2027
Technical requirements	MOI visually informs the driver about pedestrians or cyclists in close proximity within the blind spot area in front of the vehicle when the vehicle is stationary, moving off from rest in a straight line or travelling straight ahead at low speeds. The system warns the driver by two modes out of visual, acoustic and haptic, when the risk of a collision increases, e.g. when the vehicle accelerates from rest and the pedestrian or cyclist is located directly in front. MOI is active for vehicle speeds between 0 km/h and 10 km/h. It must operate in ambient light conditions down to 15 lux, i.e. also with relatively low light levels. MOI information and warning signals are default-on at vehicle start. The entire MOI or only the warning signal can be deactivated by the driver; they are automatically re-instated for the next journey. System performance is assessed in a series of dynamic and static tests with pedestrian and bicycle dummies on a test track. Dummy and/or vehicle are moved, and the system information and warning behaviour is assessed for compliance based on geometric zones of proximity.
Differences to EU cost-benefit assumptions	Note that detection of vulnerable road users to the side of the vehicle is considered under a separate technology (blind spot information).

A.1.14 Pole side impact

Pole side impact	
Technology code	PSI
Description	Crash test to improve the secondary safety of drivers in driver-side impacts with rigid narrow objects.
Regulation	UN Regulation No. 135, 01 Series of Amendments
Vehicle categories	M_1, N_1
Implementation years	2025 / 2027
Technical requirements	PSI is assessed in a 32 km/h angled (75 degrees) lateral impact against a 25 cm diameter metal pole. The positioning of the impact point in alignment with the ATD challenges particularly the driver's head protection. Doors (unless directly impacted) must remain latched. The test setup consists of a WorldSID 5^{0t}h percentile adult male ATD in the front row seat on the impacted side (typically the driver's side). The ATD must meet performance criteria relating to head, shoulder, thorax, abdomen and pelvis protection. The 01 Series of Amendments considered for implementation does not contain prescriptions to protect occupants of electric vehicles from high voltage and electrolyte leakage. Such requirements are introduced by the later 02 Series.
Differences to EU cost-benefit assumptions	None

A.1.15 Pedestrian windscreen impact

Pedestrian windscreen impact	
Technology code	PWI
Description	Head impact test to improve the secondary safety of pedestrians in impacts with the vehicle's windscreen.
Regulation	UN Regulation No. 127, 03 Series of Amendments
Vehicle categories	M_1, N_1
Implementation years	2025 / 2027
Technical requirements	PWI builds on existing pedestrian protection regulation by extending the bonnet top area for adult and child head impact to also include parts of the windscreen (up to an extended wrap around distance of 2.5 metres). A pillars and cowl area are not included. The injury criteria thresholds to be met in the windscreen area relate to head injuries and are set at the same level as for the bonnet area, which is already included in current tests.
Differences to EU cost-benefit assumptions	None

A.1.16 Reversing motion awareness

Reversing motion awareness	
Technology code	RMA
Description	Primary safety technology that aids the driver in visually observing or detecting pedestrians or cyclists behind the vehicle when reversing.
Regulation	UN Regulation No. 158, Original Version
Vehicle categories	M_1, N_1, M_2 & M_3, N_2 & N_3
Implementation years	2025 / 2027
Technical requirements	RMA requirements can be fulfilled by vision (e.g. direct vision to the rear, mirrors including close-proximity rear view mirrors, rear-view camera systems) or by awareness systems (e.g. detection system). At least one of these must be provided to the driver during backing events, which start when the reverse gear is selected and end at the manufacturer's choice when a standstill or a certain forward speed is reached, a forward gear is selected, etc. The vision assessment zone extends from 0.3 to 3.5 metres back from the vehicle's rear, across its entire width. Within this zone, objects with a height of 0.8 metres must be at least partially visible. Minimum technical specifications for camera-based systems are provided, including the optical quality, reaction times, etc. The field of detection assessment zone extends from 0.2 to 1.0 metres back from the vehicle's rear, across its entire width. Within approximately 90% of this zone, objects must be detected, and the driver informed during backing events by at least two modes out of acoustic, visual and haptic. RMA requirements are assessed by static tests with cylindrical test objects.
Differences to EU cost-benefit assumptions	The EU assessment assumed camera-based systems. The technical specifications give more flexibility to fulfil requirements by other means including mirrors or detection systems. This can potentially impact effectiveness and cost.

A.1.17 Tyre pressure monitoring

Tyre pressure monitoring	
Technology code	TPM
Description	Driver assistance technology that warns the driver of incorrect tyre pressure due to punctures or diffusion.
Regulation	UN Regulation No. 141, 01 Series of Amendments
Vehicle categories	N_1, M_2 & M_3, N_2 & N_3
Implementation years	2025 / 2027
Technical requirements	TPM visually warns the driver when one or more tyres are underinflated. Tyre pressure refill systems and central tyre inflation systems can be fitted as an alternative to TPM. TPM detects incident-related pressure loss (puncture) and underinflation (diffusion). For both cases, the detection threshold is a reduction in tyre pressure by 20%. For puncture detection, the system must detect the pressure reduction in a single tyre within 10 minutes driving time. For diffusion detection, the pressure reduction must be detected only within 60 minutes but even if it affects more than one of the vehicle’s tyres simultaneously. TPM is active for vehicle speeds from 40 km/h (N1) or 30 km/h (M2, M3, N2, N3) up to the maximum design speed. The system is approved using track tests where tyre pressure loss is simulated, and warnings provided by the system are observed.
Differences to EU cost-benefit assumptions	The EU assessment assumed a direct TPM solution. According to industry input during development of the technical regulation, this will indeed be the case for the large majority of vehicles based on the technical requirements. Therefore, no differences.

A.2 Euro NCAP protocols

The voluntary Euro NCAP safety assessment scheme is an incentive for manufacturers to fit certain technologies to their vehicles as standard equipment. Some of the technologies considered for implementation (or similar technologies) are incentivised in this way which impacts the expected fleet dispersion in absence of GB regulation.

Table 27 provides an overview of the relevant technologies and whether or not they are included in Euro NCAP assessments.

Euro NCAP recently announced[5] that van ratings (category N_1) will be updated and that the same ADAS equipment will be required as for cars (category M_1) from 2026 onward. Therefore, all ADAS systems required for cars are also marked as incentivised for vans. Secondary safety of N1 vehicles for occupants or VRUs is not being assessed by Euro NCAP.

[5] https://www.euroncap.com/en/press-media/press-releases/euro-ncap-releases-highly-anticipated-more-stringent-commercial-van-ratings-for-2023-and-announces-plans-for-safety-testing-of-hgv-s/

Vehicle categories M_2 & M_3 and N_2 & N_3 are not being assessed by Euro NCAP and therefore are not included in the table. Euro NCAP recently announced[5] that an HGV rating scheme will be introduced later in 2023. However, details of the scheme are not yet published, which is why specific incentives cannot be taken into account for this review.

Table 27: Overview of technologies incentivised by Euro NCAP by vehicle category: ■ = incentivised ☐ = not incentivised – = technology not applicable

Technology	M1	N1
ADW	■	■
AIF	☐	☐
BSI	–	–
DAW	■	■
DIV	–	–
EBC	■	■
EBP	■	■
EBV	■	■
EDR	☐	☐
ELK	■	■
ESS	☐	☐
FFI	■	☐
FOI	–	☐
ISA	■	■
MOI	–	–
PSI	■	☐
PWI	■	☐
RMA	☐	☐
TPM	–	☐

The strength of incentive to fit each of the technologies is determined by an assessment of how many Euro NCAP points can be scored as a maximum for fitment of the technology. The maximum points and weights are set in Euro NCAP's assessment protocols[6] for the respective areas of adult occupant protection, vulnerable road user protection and safety assist. The strength of incentive is classified as follows and is used to inform the modelling of voluntary uptake rates in the no-action scenario:

- No points (technology not in Euro NCAP scope): no

[6] https://www.euroncap.com/en/for-engineers/protocols/

- 0–1 weighted points: low
- >1–2 weighted points: medium
- >2–4 weighted points: high

The points awarded and the resulting strength of incentive assessments are given in Table 28 (note: identical points assumed for M_1 and N_1 based on expected 2026 upgrade of van ratings). Euro NCAP's Vision 2030[7], the most recent publication about future developments of their ratings, did not contain specific information that would require modification of any of these assessments.

Table 28: Strength of Euro NCAP incentive for manufacturers to fit technology: ■ = high ◘ = medium ☐ = low – = none

Technology	Max. points	Weight	Weighted points	M1	N1
ADW	2	0.2	0.4	☐	☐
AIF	–	–	–	–	–
BSI	–	–	–	–	–
DAW	2	0.2	0.4	☐	☐
DIV	–	–	–	–	–
EBC	9	0.2	1.8	◘	◘
EBP	9	0.2	1.8	◘	◘
EBV	9	0.2	1.8	◘	◘
EDR	–	–	–	–	–
ELK	3	0.2	0.6	☐	☐
ESS	–	–	–	–	–
FFI	8	0.4	3.2	■	–
FOI	–	–	–	–	–
ISA	3	0.2	0.6	☐	☐
MOI	–	–	–	–	–
PSI	6	0.4	2.4	■	–
PWI	18	0.2	3.6	■	–
RMA	–	–	–	–	–
TPM	–	–	–	–	–

[7] https://cdn.euroncap.com/media/74468/euro-ncap-roadmap-vision-2030.pdf

Appendix B Calculation methods and models

This appendix describes the structure of the models developed to quantify and monetise the primary impacts (the Clustered Impact Appraisal Model (CIAM), bespoke software developed as part of the iMAAP suite, and the Economic Appraisal Model (EAM), implemented in Excel) and details the calculation methods implemented within them.

Subsequent Appendix C describes the data that was input into CIAM (such as baseline casualty numbers, technology effectiveness estimates and cost estimates) to calculate impacts for the present study. Appendix D provides summary tables of results calculated by CIAM and EAM using that input data.

B.1 Model structure

A cost-benefit model toolchain was developed to quantify the impacts of individual technologies and combinations of technologies over a user-specified appraisal period, and then to monetise those impacts, and report:

- Number of casualties prevented (killed, seriously injured, slightly injured)
- Number of collisions prevented (fatal, serious, slight, damage-only)
- Mass of emissions avoided (CO_2, NO_x and PM_{10})
- Litres of fuel (petrol, diesel) and kilowatt-hours of electricity saved
- Hours of journey time saved
- Technology costs (fitment, maintenance and repair)
- Net present value (NPV)
- Benefit-cost ratio (BCR)
- Equivalent annual net direct cost to business (EANDCB)

Each analysis compares the user-selected case for the mandatory introduction of the technology packages with a 'business-as-usual' case in which adoption of the technology is voluntary (i.e. market driven).

User input determines the forecast uptake and costs of the technologies considered, future traffic, emission and casualty baselines alongside various other factors. The toolchain allows sensitivity analysis by varying the input data for the casualty baseline (see Appendix C.5.1), the technology effectiveness (see Appendix C.6.1) and the fitment and maintenance costs (see Appendix C.3).

For each technology the software undertakes a 'dispersion' calculation: the forecast number of new vehicles fitted with each technology in each year and the cumulative number of equipped vehicles (allowing for vehicle replacement), using specified uptake models.

Most impacts are calculated using a baseline and effectiveness factors. The software weights the input effectiveness factor by the forecasted fleet penetration, uses sequential multiplication to combine the effectiveness factors for each technology (to avoid double counting of effects from different technologies), and then calculates the resulting change compared with the baseline. Cost impacts, for which there is no baseline, involve multiplication of unit costs by the forecasted fitment rate, with a correction for costs that would be shared between technologies.

Because of the number of possible combinations of technologies, baseline scenarios and user selected parameters it was decided to implement the impact calculations in bespoke software as a new module in TRL's iMAAP package, the Clustered Impact Appraisal Model (CIAM). The economic analysis of the forecast impacts is undertaken in a bespoke Excel model, the Economic Appraisal Model (EAM), developed to allow compatibility with DfT's other appraisal tools. The model toolchain is summarised in Figure 6.

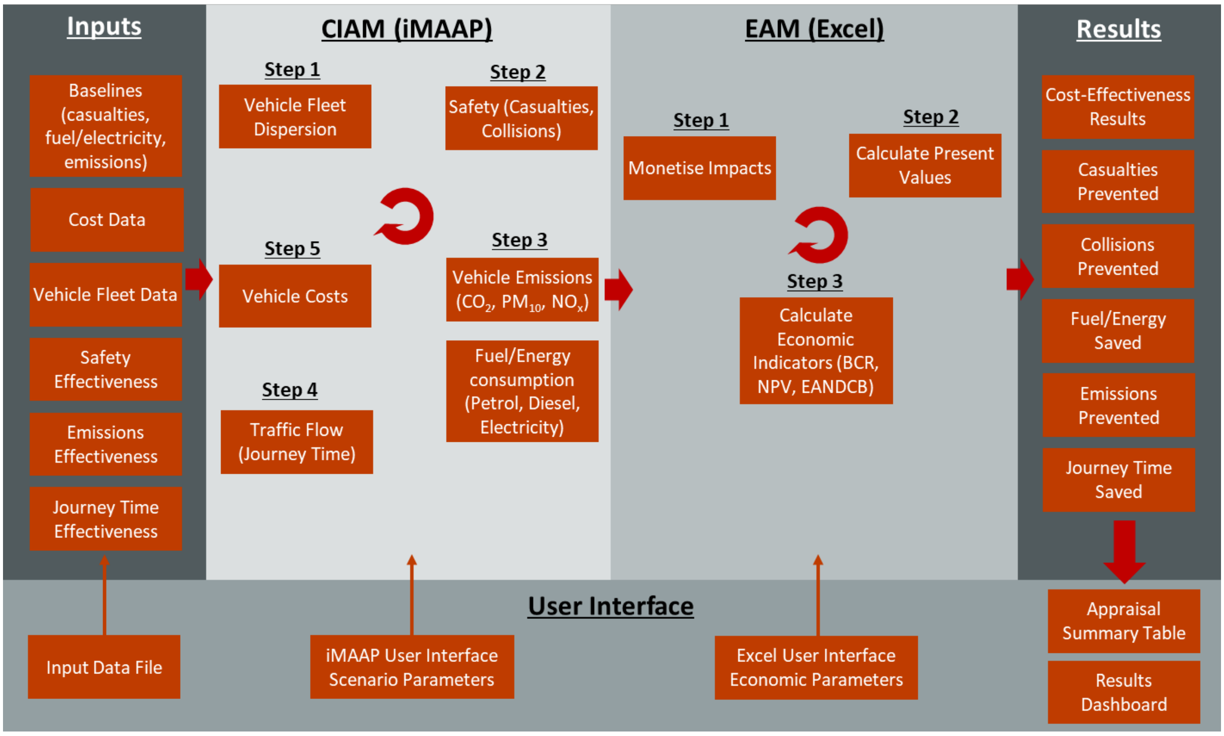


Figure 6: Structural overview of bespoke toolchain developed for this project, comprising of CIAM and EAM

The main inputs for the model are data tables providing (see Appendix C for more detail):

- Baseline data from DfT's National Transport Model (NTM) and Road Carbon and Fuel Fleet (RoCaFF) model providing forecast vehicle numbers, vehicle kilometres driven, travel time, fuel consumption and emissions year-on-year up to 2050
- Casualty baselines and collision constants
- Casualty target populations: the number of potentially affected vehicle occupants or VRUs and whether they are in the target population of each vehicle category and technology
- Technology effectiveness estimates that quantify the change that each technology would be expected to have on the baseline

- Unit cost impacts for fitment and ongoing operational aspects such as repair and maintenance by technology and vehicle category

The baseline data tables from NTM and RoCaFF are categorised by vehicle category (Car (M1), Van (N1), HGV (N2N3), Bus and Coach (M3)) and road type ('motorway', 'trunk road', 'A road', 'minor road'). The NTM provides estimates for a range of scenarios; for this project data was chosen by the DfT for 'vehicle-led decarbonisation', 'core' and 'mode-balanced decarbonisation'.

Other model inputs are:

- Parameters to specify the forecast rate of voluntary uptake for each technology
- Adjustment factors for target populations for specific technologies to address under-reporting, where supported by evidence from the literature review
- Parameters to adjust unit cost values to reflect any shared costs when multiple technologies are fitted (e.g. having a sensor in common)
- Parameters to specify the extent to which future unit costs will fall with increased adoption rates

A user interface (see Figure 7) enables the CIAM user to specify the requirements for each analysis run: the appraisal years, technologies and vehicle categories to be included, implementation years for each technology, casualty baseline scenario selection and technology effectiveness and cost ranges to be used (H/M/L).

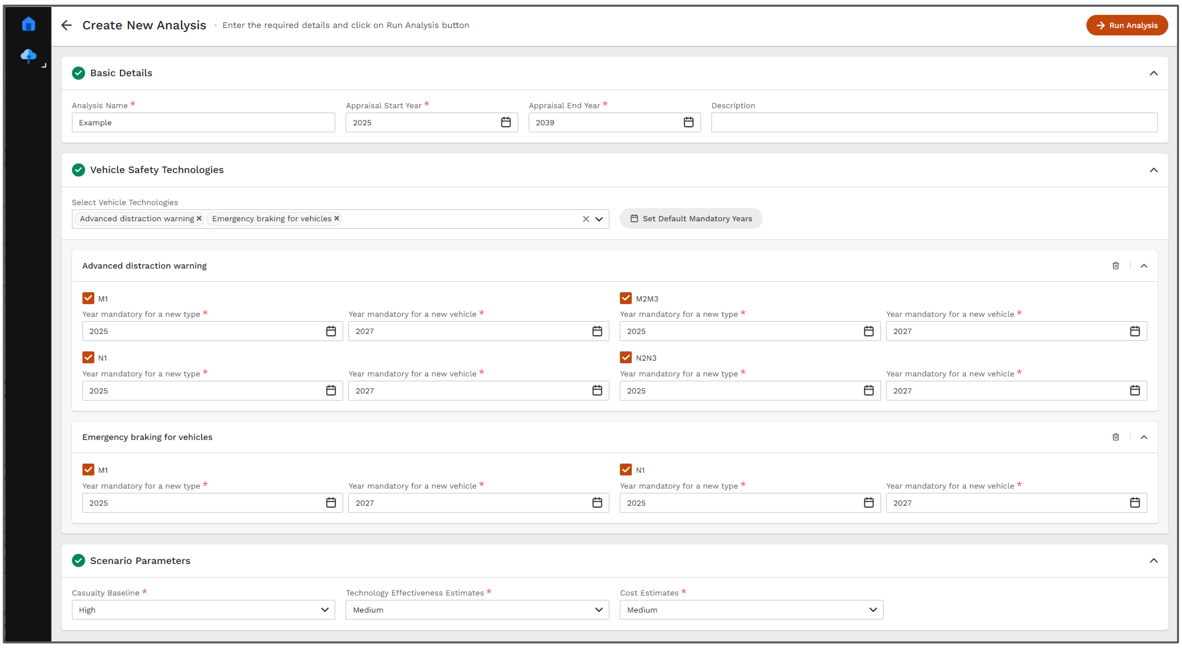


Figure 7: CIAM – user interface for creating analyses

The output from the CIAM software is a spreadsheet with tables quantifying the annual impacts for each category (number of avoided casualties and collisions, technology costs for users, emissions saved, fuel/energy saved, journey time changes) for the chosen scenario compared to the 'business-as-usual' case, both in total and segmented by vehicle category.

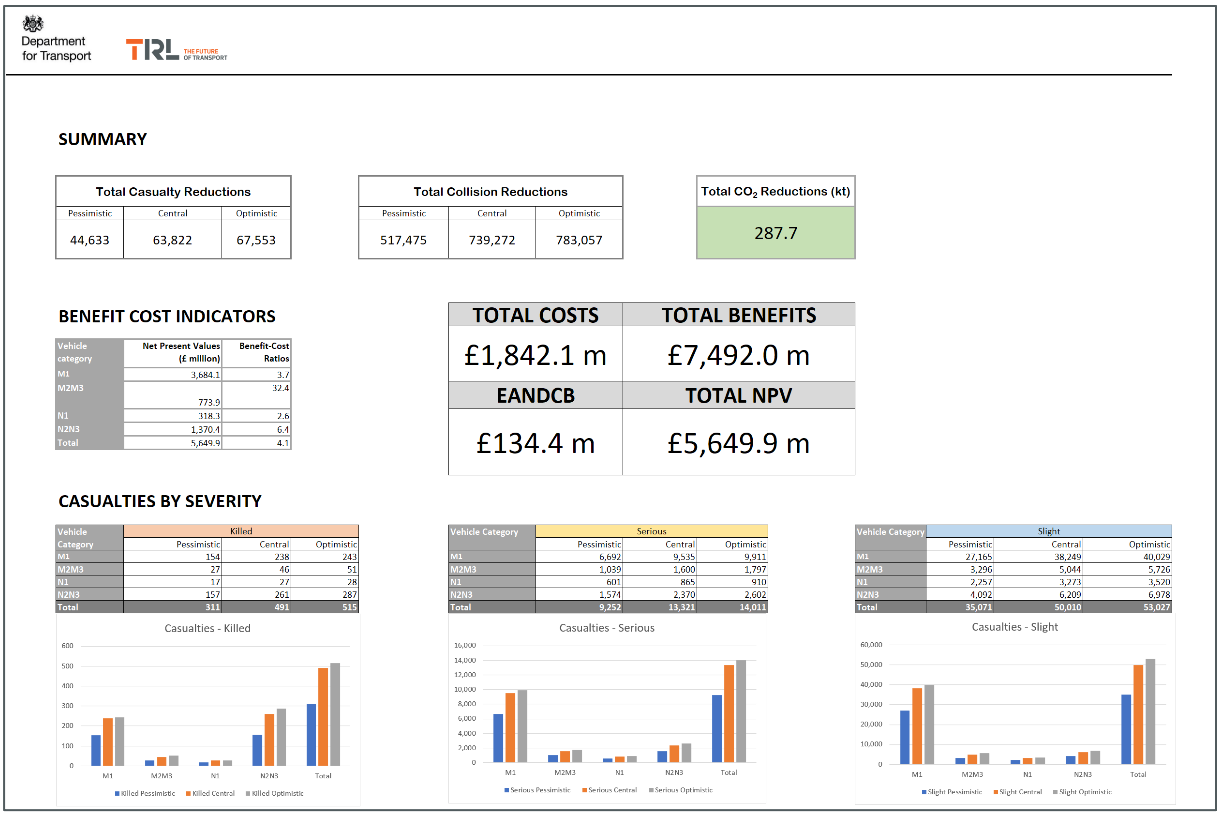
This spreadsheet provides the input to EAM. This model applies the standard calculations required for transport appraisal, in particular:

- Monetising the non-cost impacts by multiplying impacts by the appropriate unit costs (value per casualty avoided, value per collision avoided, damage costs for avoided NOx and PM, the carbon price for greenhouse gas savings, value of time)
- Adjusting prices to a user-specified base year
- Calculating annual values for each year in the appraisal period for costs provided for a single year
- Discounting future costs and benefits using the required discount rate (3.5% or 1.5% as appropriate)
- Differentiating between private and business user costs
- Calculating fuel duty and VAT impacts
- Calculating the overall NPV and BCR for the scenario. The NPV provides a measure of the overall impact of an option. The BCR provides a measure of the benefits relative to costs.
- Calculating the EANDCB

User inputs (for which default values are incorporated) are:

- Price base year – the year values are deflated to
- Base year – the year values are discounted to
- Discount rate (risk to life/ willingness to pay)
- Discount rate (others)
- Technology package (from a drop-down menu)

A user guide in EAM describes the required user inputs, software inputs (from CIAM) and the outputs. Figure 8 shows the results dashboard of the model used to communicate the most important results to the user.



Department for Transport

SUMMARY

Total Casualty Reductions		
Pessimistic	Central	Optimistic
44,633	63,822	67,553

Total Collision Reductions		
Pessimistic	Central	Optimistic
517,475	739,272	783,057

Total CO_2 Reductions (kt)
287.7

BENEFIT COST INDICATORS

Vehicle category	Net Present Values (£ million)	Benefit-Cost Ratios
M1	3,684.1	3.7
M2M3	773.9	32.4
N1	318.3	2.6
N2N3	1,370.4	6.4
Total	5,649.9	4.1

TOTAL COSTS	TOTAL BENEFITS
£1,842.1 m	£7,492.0 m
EANDCB	TOTAL NPV
£134.4 m	£5,649.9 m

CASUALTIES BY SEVERITY

Vehicle Category	Killed		
	Pessimistic	Central	Optimistic
M1	154	238	243
M2M3	27	46	51
N1	17	27	28
N2N3	157	261	287
Total	311	491	515

Vehicle Category	Serious		
	Pessimistic	Central	Optimistic
M1	6,692	9,535	9,911
M2M3	1,039	1,600	1,797
N1	601	865	910
N2N3	1,574	2,370	2,602
Total	9,252	13,321	14,011

Vehicle Category	Slight		
	Pessimistic	Central	Optimistic
M1	27,165	38,249	40,029
M2M3	3,296	5,044	5,726
N1	2,257	3,273	3,520
N2N3	4,092	6,209	6,978
Total	35,071	50,010	53,027

Figure 8: EAM – example output on results dashboard (note: values shown do not reflect actual results)

The following sections provide more detail on the calculations performed by the models.

B.2 Calculation modules

B.2.1 Fleet dispersion analysis (CIAM)

Figure 9 gives an overview of the inputs (grey), calculations (black) and outputs (orange) from the fleet dispersion model. The aim of this process is to estimate the number of vehicles in the fleets in each year equipped with each technology, for both voluntary and mandatory fitment.

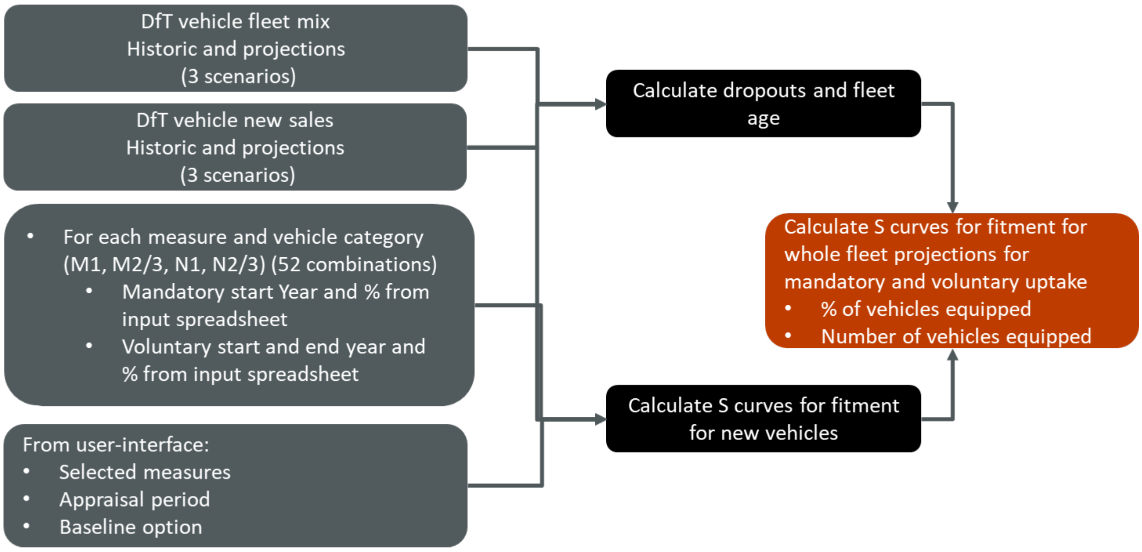


Figure 9: Fleet dispersion method

The inputs to the process are the historic and future projections of the fleets and new vehicles in the fleets for GB (see Appendix C.4).

Each year there are new registrations and vehicles ‘drop out’ of the fleet. Each year a percentage of the new vehicles entering the fleet has a given technology, and this percentage increases each year. This uptake of measures was modelled using an S-shaped curve. This was similar to those used in EU CBA (Seidl M, 2017). For each technology there is a S-curve type distribution of fitment in new vehicles; for example, initially the rate of fitment is relatively low, and then increases so the technology is commonplace amongst new vehicles, and then there are some vehicles which will be later in fitting technology on some vehicle models.

The combined effect of new vehicles joining the fleet, the dropouts and the fitment rate of technology to new vehicles was combined to estimate the fitment rate of the entire fleet.

As shown in the example chart below, although 5% of new vehicles are equipped in the early years, there is a lag in this level of equipment penetrating the entire fleet due to the relatively small percentage of new vehicles each year. As the percentage of new vehicles equipped increases, the percentage of the entire fleet with the technology increases more rapidly.

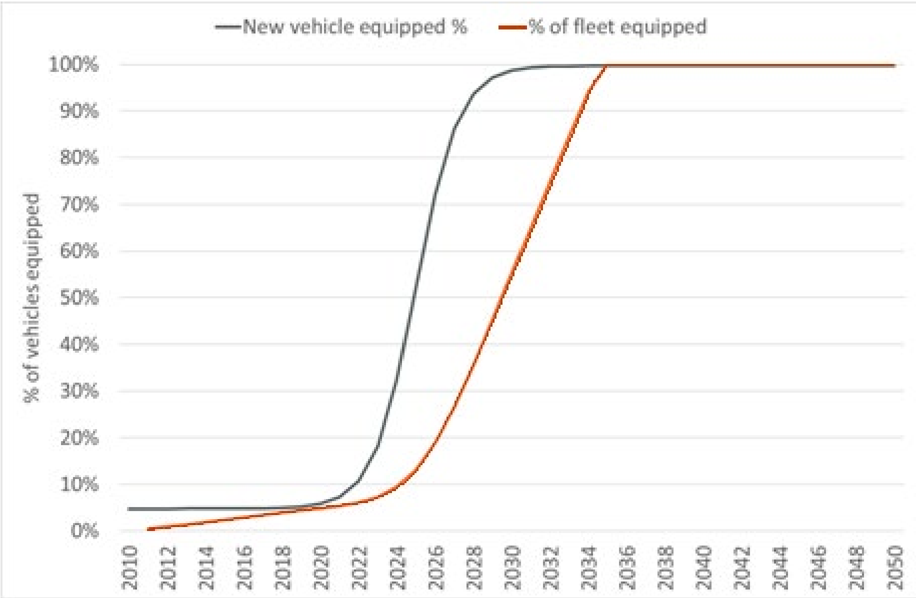


Figure 10: Example of percentage of new vehicles and of entire fleet equipped

B.2.2 Casualty and collision analysis (CIAM)

B.2.2.1 Overview

The casualty benefit modelling is split into two parts:

Part 1 uses the output from the fleet dispersion modelling (for voluntary and mandatory take ups), the casualty target populations and the effectiveness estimates to produce a percentage of casualties prevented each year for the combination of measures selected.

Part 2 applies these percentages for each year to the baseline casualties to calculate the casualty savings for the voluntary and mandatory scenarios each year and the difference between them.

The casualty benefits are calculated for each year and for each severity and for all casualties, VRUs and vehicle occupants. Outputs also give the number of casualties in M1, M2M3, N1 and N2N3 collisions separately; note that these categories overlap and sum to more than the total number of casualties since a casualty might be in a collision involving, for example, both an M1 and N1 vehicle.

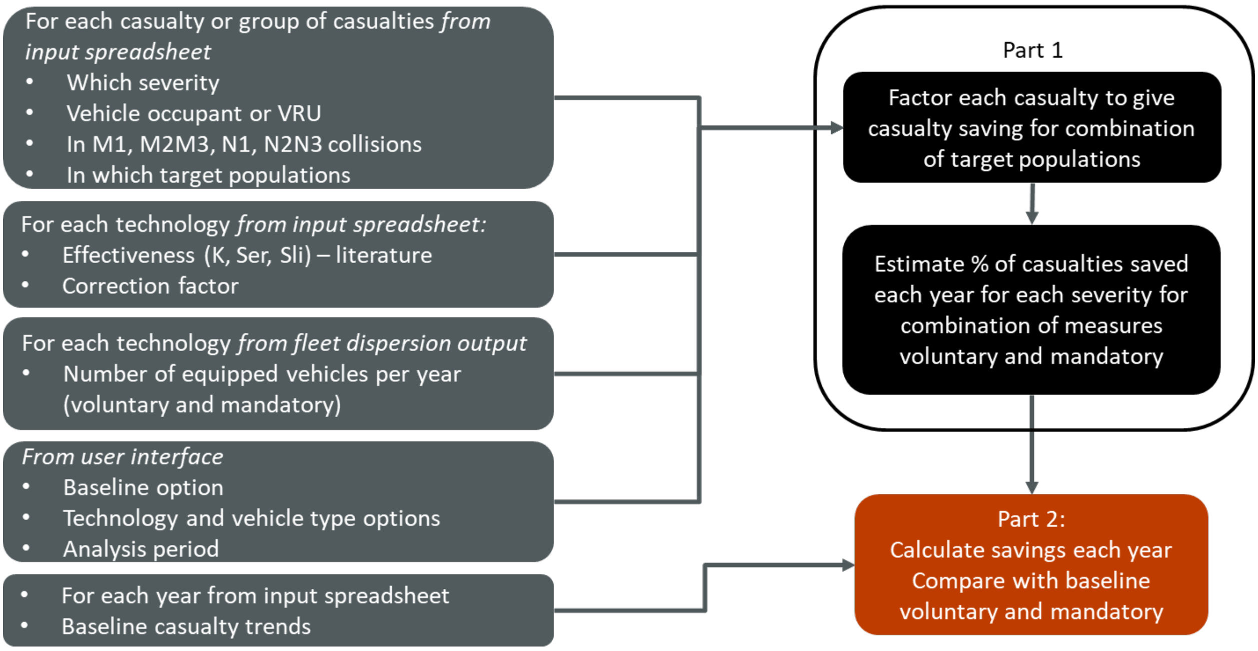


Figure 11: Overview of casualty benefit modelling

The inputs to the calculation are (shown in grey boxes in Figure 11):

- Selection of vehicle technologies applied to vehicle types and analysis period
- Vehicle fleet/safety systems penetration for each year and technology, for voluntary and mandatory (see Appendix B.2.1)
- The number of casualties with each combination of target populations (see Appendix C.5.2)
- Casualty correction factors to factor for STATS19 records of vehicles with unknown weights and collisions with under-reported contributory factors or without any contributory factors noted (see Appendix C.5.2.2)
- The effectiveness of each technology (see Appendix C.2.2)
- Baseline scenarios (high, medium, low) and split by VRU/vehicle occupant and M1/M2M3/N1/N2N3 collisions (see Appendix C.5.1)

A description of the method used in part 1 to estimate the percentage of casualties prevented from the combination of selected technologies is shown in Figure 12.

The calculations were done for individual casualties or groups of casualties with the same characteristics, i.e. part of the same combinations of target populations. This method gives each casualty a fraction prevented, which when summed over all casualties gives the total savings.

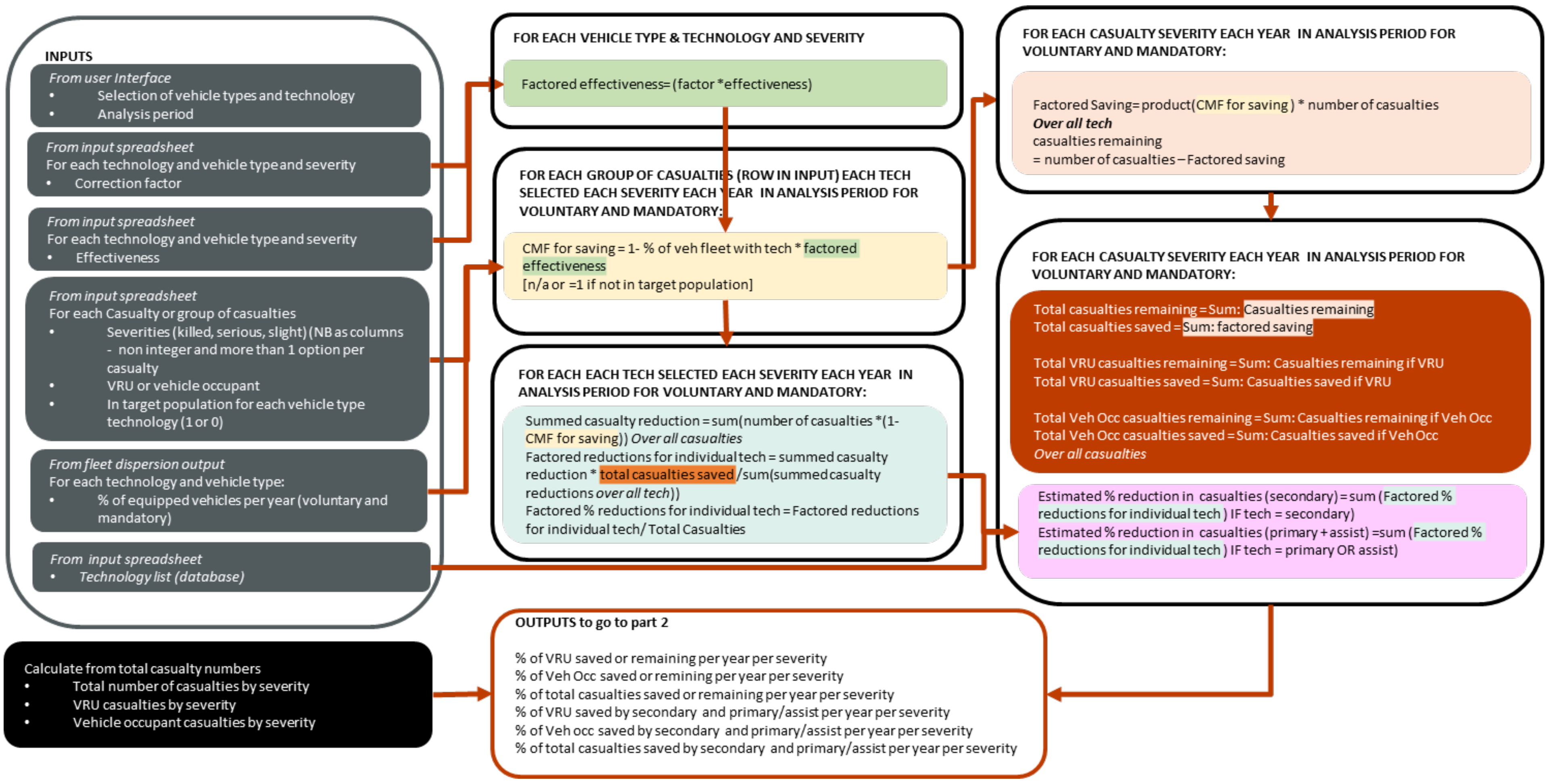


Figure 12: Casualty benefit modelling part 1, note: CMF = Crash Modification Factor

A schematic of the calculations carried out in part 2 to calculate the casualty savings for the voluntary and mandatory scenarios each year and the difference between them is shown in Figure 13.

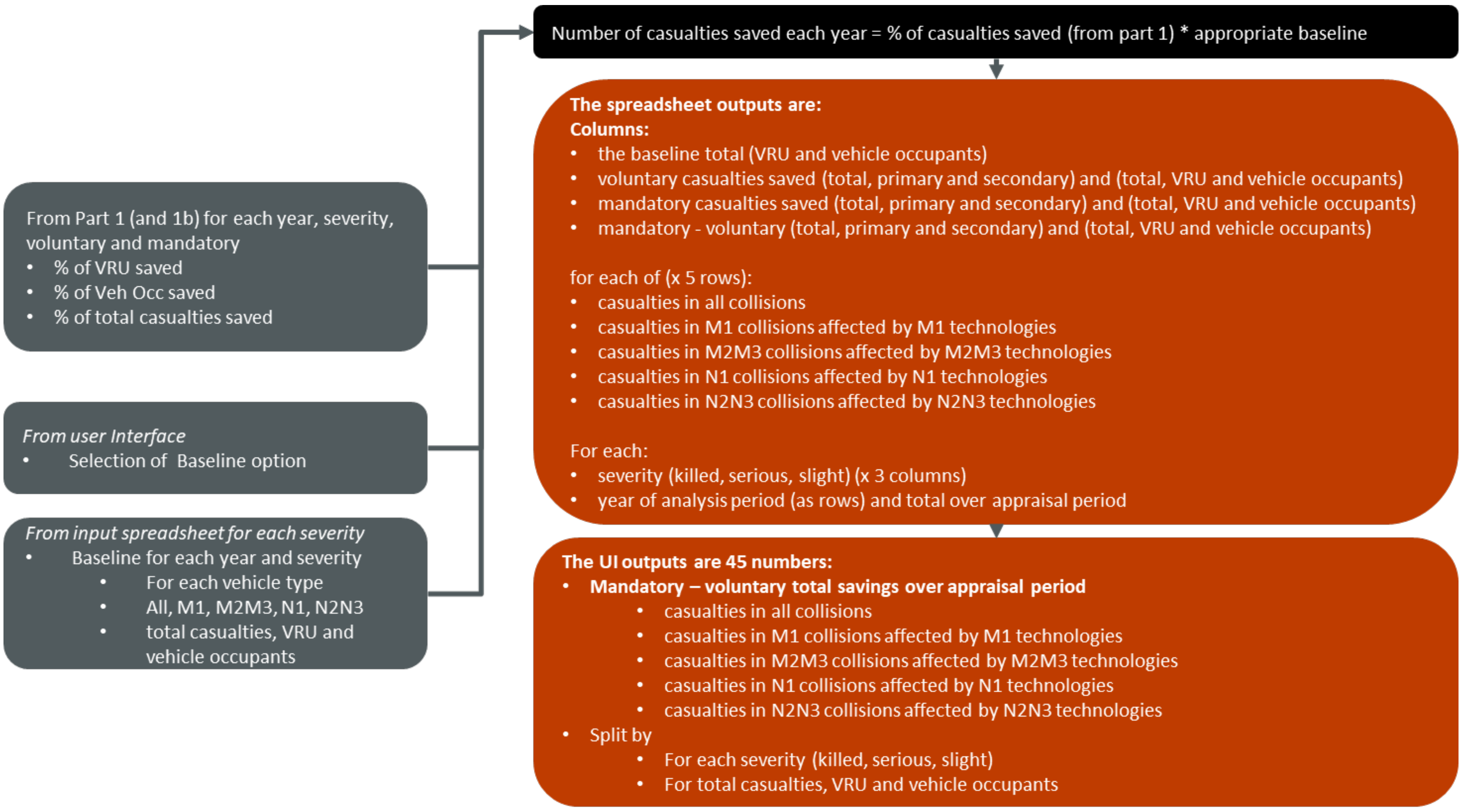


Figure 13: Casualty benefit modelling part 2

B.2.2.2 Method

Note that all numbers below are just exemplary and do not reflect real input values.

Part 1

The steps below were done for each year, severity, mandatory and voluntary, with results separated for VRUs and vehicle occupants and for casualties in M1 collisions, casualties in M2M3 collisions, casualties in N1 collisions and casualties in N2N3 collisions.

1. Calculate a **factored effectiveness** estimate which accounts for the under-classification of some of the target populations. This under-classification is because either (a) there are collisions that do not have target populations recorded (b) there are goods vehicles with unknown weights or (c) literature suggests a greater percentage of collisions in the target population than estimated from STATS19 (see Section C.5.2.2 for more details). The factored effectiveness is equal to the effectiveness multiplied by the correction factor as shown in Table 29. For example for M1_ADW with an effectiveness of 10% and a correction factor of 1.5 gives a factored saving of 15% or 0.15.

Table 29: Casualty calculation example–- Step 1 calculate factored effectiveness

	M1_ADW	M1_AIF	M2M3_DAW	M2M3_EBC
% of vehicles in year with tech	50%	50%	50%	25%
technology effectiveness (killed)	10%	20%	20%	2%
technology correction factor (killed)	1.5	1.5	1.0	1.0
factored effectiveness (reduction)	15%	30%	20%	2%

2. Calculate a Crash Modification Factor (CMF) for each casualty based on the factored effectiveness and the percentage of vehicles equipped with the technology. CMFs are used to indicate what proportion of casualties are remaining or ‘unsaved’ by a given intervention. This is 1 – the factored effectiveness multiplied by the percentage of vehicles with technology. For example, for M1_ADW if 50% of vehicles are expected to have ADW technology (which has a factored saving of 15% or 0.15) then the CMF is 1 – 50% × 0.15 = 0.925. This is equivalent to a saving of 7.5% (i.e. half of the 15% saving because only half of the vehicles are estimated to have the technology in the example year).
3. Combine factors for combination of target populations for each casualty to give an overall CMF. This is the product of the CMFs for each technology. The CMFs can be applied sequentially. For example: if the first technology has a CMF of 0.925 and reduces the target population from 100 to 92.5 then a second technology with a CMF of 0.85 applies to the remaining 92.5 giving 0.7863. Applying these factors in any order gives the same result.

4. Calculate the casualty saving for each row of casualties in the target population by multiplying 1 – the overall CMF by the number of casualties. For example (1–0.7863) × 2 = 0.4274).
5. Calculate the total savings over all casualties by summing the casualties prevented. In the example in Table 30 the total saving from the 5 casualties is 0.94, i.e. nearly one casualty is estimated to be prevented.
6. Calculate the percentage of casualties prevented (this is used in part 2). In the example in Table 30 the casualty saving of 0.94 from an initial 5 casualties represents a saving of 18.7%.

Table 30: Casualty calculation example – steps 2 to 6 (note: CMF = 1 where casualties not in target population of technology)

Target pop. row reference	Number killed	CMF M1_ADW (step 2)	CMF M1_AIF (step 2)	CMF M2M3_DAW (step 2)	CMF M2M3_EBC (step 2)	Overall CMF (step 3)	Combined saving (step 4)
1	2	0.925	0.850	1	1	0.7863	0.43
2	1	0.925	0.850	1	1	0.7863	0.21
3	1	1	1	1	1	1	0
4	1	0.925	0.850	0.90	0.995	0.7041	0.30
total killed (step 5)	**5**	–	–	–	–	–	**0.94**
% of total (step 6)	**100**	–	–	–	–	–	**18.7**

7. An additional step was included to separate the casualty savings into those from primary or assist and those from secondary safety. This method was based on how iRAP deal with multiple countermeasures (iRAP, 2013).The effectiveness was estimated for each of the relevant technologies and then summed for primary/assist and secondary. This is used in the collision benefit modelling (see Appendix B.2.2.3).

Table 31: Casualty calculation example – step 7

	M1_ADW	M1_AIF	Overall KSI remaining	Overall KSI saving
CMF for saving	0.925	0.850	0.925 × 0.850 = 0.78625	1 – 0.7863 = 0.21375
Effectiveness (1 – CMF)	0.075	0.15	-	0.075 + 0.15 = 0.225*
Factored effectiveness**	0.075 / 0.225 × 0.2138 = 0.07125	0.15 / 0.225 × 0.2138 = 0.1425	1 – 0.2138 = 0.78625	0.07125 + 0.1425 = 0.21375

* Note that this is greater than the saving calculated by multiplying the CMFs in above row which is why they are factored in next row

** So that sum of effectiveness for each technology sums to same effectiveness calculated by multiplying CMFs

Part 2

The number of casualties estimated to be prevented each year from voluntary or mandatory adoption of technologies is calculated by multiplying the percentage of casualties prevented (from part 1) by the appropriate baseline. This is calculated for the following combinations:

- voluntary casualties prevented (total, primary and secondary) and (total, VRU and vehicle occupants). The casualty savings were split into VRU and vehicle occupants so that benefits could be assessed separately.
- mandatory casualties prevented (total, primary and secondary) and (total, VRU and vehicle occupants)
- mandatory – voluntary (total, primary and secondary) and (total, VRU and vehicle occupants)

for each of:

- casualties in all collisions
- casualties in M1 collisions affected by M1 technologies
- casualties in M2M3 collisions affected by M2M3 technologies
- casualties in N1 collisions affected by N1 technologies
- casualties in N2N3 collisions affected by N2N3 technologies

For each:

- severity (killed, serious, slight) (x 3 columns)
- year of analysis period (as rows) and total over appraisal period

B.2.2.3 Collision benefit modelling (CIAM)

There are additional savings in avoiding collisions in addition to savings due to casualties, for example, police costs and damage to infrastructure (DfT, n.d.).

Creating baselines for the number of collisions and applying the casualty-based technology effectiveness to target population would be extremely complex. Therefore, the number of collisions that would be prevented was estimated based on the casualty savings as described above and the average number of casualties of each severity per fatal, serious and slight collision. For example, on average a fatal collisions includes 1.06 fatalities, 0.32 seriously injured and 0.31 slightly injured and a serious collision on average includes 1.08 seriously injured and 0.45 slightly injured (see Table 56 in Appendix C.5.3).

The average number of casualties per collision by severity and the number of damage-only collisions per personal injury accident (PIA) were used together with the casualties prevented from primary/assist technology measures to estimate the number of collisions prevented for each road type as follows:

1. **Fatal collisions prevented** = killed casualties prevented / average killed casualties per fatal collision × proportion of fatal collisions on each road type. For example, if there was a saving of 100 fatalities, this would be an estimated saving of 94 (=100/1.06) collisions.
2. **Serious collisions prevented** = (serious casualties prevented – serious casualties in fatal collisions) / average serious casualties per serious collision × proportion of serious collisions on each road type. For example, the 94 fatal collisions estimated in step 1 would also generate 30 (=94 × 0.32) seriously injured. So an example casualty saving of 500 seriously injured would have 470 (=500-30) serious casualties in serious collisions, which would be the result of an estimated 435(=470/1.08) serious collisions.
3. **Slight collisions prevented** = (slight casualties prevented – slight casualties in fatal and serious collisions) / average slight casualties per slight collision × proportion of slight collisions on each road type
4. **Damage-only collisions prevented:**
    a. Sum number of collisions for motorways, rural and urban for all severities
    b. Apply the average damage-only collisions per PIA for each road type

This method assumes that the number of casualties per collision and the number of damage-only collisions per injury collision is the same for each collision type and for future years.

Example casualty benefit calculation

In this example assume that:

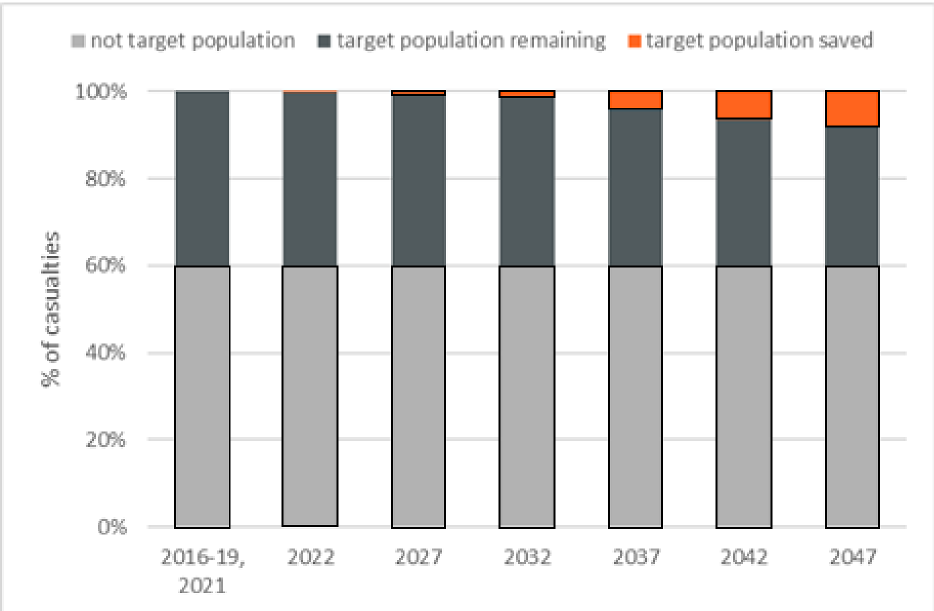
- The effectiveness of the technology is 20% of casualties in the target population equipped with the vehicle technology
- 40% of casualties are in the target population
- The percentage of vehicles with the technology increase from 1% in 2022, through 50% in 2037 and to 99% in 2047

In each year the estimated casualty saving is the percentage of the vehicles with the technology multiplied by the percentage in the target population and the effectiveness.

E.g. in 2037 when 50% of vehicles have technology then the saving is 50% × 40% × 20% = 4%, the target population remaining is therefore 40% - 4% = 36%, and the casualties not in the target population remain unchanged.

	2016-19, 2021 (actual data)	**2022** (model)	**2027** (model	**2032** (model)	**2037** (model	**2042** (model	**2047** (model
% of vehicles with tech (mandatory)	**-**	**1%**	**5%**	**15%**	**50%**	**80%**	**99%**
Target population saved	**-**	0.1%	0.4%	1.2%	4.0%	6.4%	7.9%
Target population remaining	**40%**	39.9%	39.6%	38.8%	36.0%	33.6%	32.1%
Not target population	**60%**	60%	60%	60%	60%	60%	60%

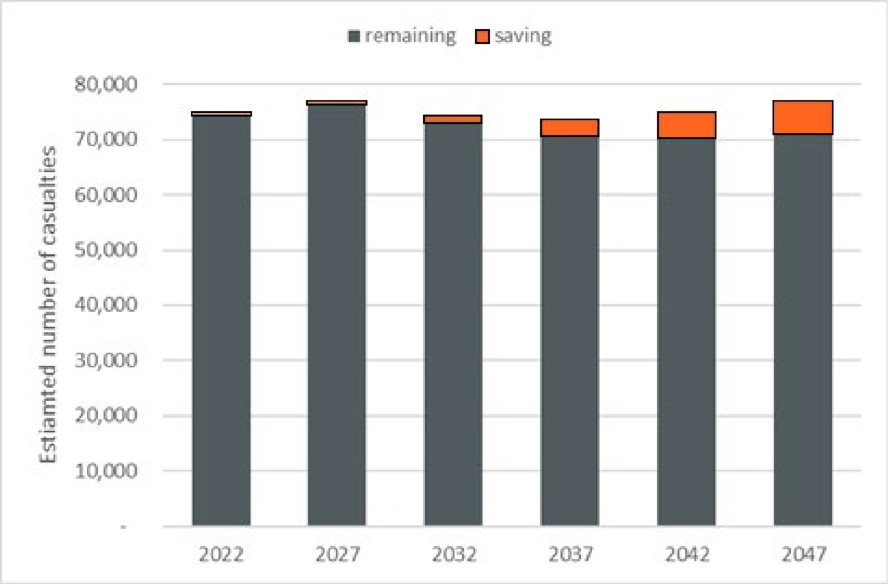
As the percentage of vehicles in the fleet with the technology increases the target population saved increases as shown below.



The percentage savings are then applied to the baseline scenario.

E.g. in 2037, the example saving was 7.9%. This is applied to the baseline (75,018 × 7.9%) to give a saving of 4,801. Therefore there are 70,217 casualties remaining (75,018 - 4,801).

	2022	2027	2032	2037	2042	2047
Baseline (Serious, medium)	74,581	76,753	74,147	73,655	75,018	77,083
Casualty saving	60	307	890	2,946	4,801	6,105
Casualties remaining	74,521	76,446	73,258	70,709	70,217	70,978



B.2.3 *Emissions analysis (CIAM)*

Technologies potentially affecting emissions are ISA and TPM. The emissions considered were:

- Tailpipe greenhouse gases (CO_2e)
- Oxides of nitrogen (NO_x)
- Particulate Matter (as PM_{10}) (tailpipe, tyre and brake wear)

Tailpipe CO_2e arises from fuel combustion, so any changes would be in direct proportion to any changes in fuel consumption that might arise.

NOx emissions can be affected by a vehicle's drive cycle, being worse with congested traffic or repeated acceleration. Technologies that affect driving style might therefore affect emissions.

Tailpipe PM can be affected in a similar way to NOx by changes in driving style. However, PM is also produced from the abrasion of tyres and brakes, so is produced by EVs as well as by ICEs. Brake and tyre PM would therefore be expected to be affected by any technology that affects vehicle weight or drive cycle, and also by under-inflation of tyres. EVs are heavier than their equivalent ICE model, so their non-tailpipe emissions can be higher; on the other hand, EVs employ regenerative braking which would be expected to reduce brake pad wear (Air Quality Expert Group, 2019). However, this is an area in which research is at an early stage and so the model does not attempt to analyse differences between EVs and ICEs.

The method for calculating emissions is similar in principle for all emission types:

- Baseline data for each of the tailpipe emissions were obtained from DfT, using forecast emissions based on the National Transport Model scenarios. The baseline data were segmented by vehicle category ('Car', 'Van', 'HGV', 'Bus and Coach') and road type ('Motorway', 'Trunk', 'A road', 'minor'); therefore the effectiveness factors are segmented by vehicle and road type using the same categories.
- Evidence from the literature review was used to compile a table of 'effectiveness factors' that reflect the percentage change in emissions that ISA or TPM might cause, relative to the baseline (see Appendix C.6.2). The technology effectiveness factors are multiplied by the technology's fitment rate for each year, using the output from the dispersion calculation (see Appendix B.2.1), to arrive at weighted effectiveness factors. To avoid double counting impacts when multiple technologies are applied to the same vehicles, the weighted effectiveness factors for each technology are multiplied sequentially with each other to produce a combined factor.
- To calculate the impacts for a given year the combined factor is multiplied with the baseline to obtain the overall change (positive or negative) that would be expected, compared with the baseline in that year.
- Impacts are calculated for two cases, the 'business-as-usual' case in which the technologies are adopted on a voluntary/ market-led basis and the mandatory case in which their fitment is required by regulation. The difference between the outputs from the two cases reflects the overall impact that is taken forward for economic analysis.

DfT baseline data was only available for tailpipe PM; therefore, baselines for Tyre and Brake PM have to be created within the software. This is done by multiplying the forecast km driven by each vehicle type on each road type (from NTM data provided by DfT) by an emission factor, which is the amount of PM_{10} (in mg) of each type produced per kilometre, for each vehicle and road category. The emission factors were calculated by TRL, following a method recommended in EEA EMEP/EEA air pollutant emission inventory guidebook (Ntziachristos & Boulter, 2019), which uses speed-based emission factors for different vehicle types.

Once the tyre and brake baselines are created, they are then processed similarly to the tailpipe emissions. i.e. technology effectiveness for tyre or brake is weighted for the fitment rate of the relevant technologies, then combined by sequential multiplication for each technology.

Summary of process:

- Inputs:

- User selected baseline scenario for CO_2e, NO_x and tailpipe PM (DfT)
- Effectiveness factors for each emission, for user specified range (H/M/L) (TRL)
- Technology fitment rate, calculated from previous CIAM step
- Traffic vehicle-km baseline for selected baseline (DfT)
- Emission factors for tyre and brake wear PM10 (TRL calculation)

- Outputs (which serve as inputs for EAM):
  - Table of forecast annual changes in emissions, in total and segmented by vehicle category
- Limitations
  - eVs are not treated separately from ICEs in the PM analysis.
  - Effectiveness is assumed to scale linearly with fitment rate; however, the individual impact of technologies that affect driver behaviour might be greater when there is a greater level of adoption and, for example, lower top speeds become the norm.

B.2.4 Fuel and energy consumption analysis (CIAM)

To calculate the impact of the ISA and TPM on running costs it is necessary to calculate the change in consumption of petrol and diesel (in litres), for ICE vehicles, or electricity (kWh) for EVs. The method used to calculate changes in energy consumption is identical to that used for emissions (see Appendix B.2.3).

Because tailpipe CO_2 arises from the fuel consumed, the emissions are directly proportional to petrol or diesel consumption. The technology effectiveness parameters previously developed for calculating the CO_2 emissions are therefore also used to calculate changes in petrol and diesel consumption.

There are some important differences between eVs and ICE vehicles in how energy consumption is affected by drive cycle, such as the use of regenerative braking and differences between the speed- energy consumption curve of these two drivetrains. For this reason the model was designed to calculate energy savings for eVs separately, using a table of technology effectiveness specifically for electricity consumption. In principle this means that impacts on the energy consumption of eVs can be treated separately from ICEs, if sufficient evidence can be identified to take account of differences between ICE and EV drivetrains.

Electricity consumption by vehicle and road type is calculated by multiplying the baseline (for mandatory and voluntary cases) by the corresponding combined technology effectiveness parameters (weighted by fitment rate). The difference between the two is calculated by vehicle and road type to calculate the annual savings and used for the output.

Summary of process:

- Inputs:

- User selected baseline scenario for petrol, diesel and electricity consumption (DfT)
- Combined, weighted effectiveness factors for CO2, taken from emission calculations.
- Effectiveness factors for electricity consumption, for user specified range (H/M/L) (TRL)
- Technology fitment rate, calculated from previous CIAM step

- Outputs (which serve as inputs for EAM):
  - Table of forecast annual changes in petrol, diesel and electricity, in total and segmented by vehicle category
- Limitations:
  - Effectiveness is assumed to scale linearly with fitment rate; however, the individual impact of technologies that affect driver behaviour might be greater when there is a greater level of adoption and, for example, lower top speeds become the norm.

B.2.5 Journey time analysis (CIAM)

ISA, a technology that controls a vehicle's speed and potentially otherwise affects how it is driven, could affect journey times. If speeds are reduced when traffic is free flowing, then journey times could increase. However, in congested traffic, reducing the speed differential between vehicles could result in smoother traffic, reducing journey times. CIAM was therefore designed to allow changes in journey time from ISA to be taken into account. The method used to calculate changes in journey times is identical to that used for emissions (see Appendix B.2.3), apart from there only being a single technology to consider which is why sequential multiplication of different effectiveness factors is not necessary.

Summary of process:

- Inputs:
  - User selected baseline scenario for travel time (DfT)
  - Effectiveness factors for travel time, for user specified range (H/M/L) (TRL)
  - Technology fitment rate, calculated from previous CIAM step
- Outputs (which serve as inputs for EAM):
  - Table of forecast annual changes in journey time, in total and segmented by vehicle category
- Limitations:
  - Effectiveness is assumed to scale linearly with fitment rate; however, the individual impact of technologies that affect driver behaviour might be greater when there is a greater level of adoption and, for example, lower top speeds become the norm.

  - This limitation will particularly affect journey time as any benefits from smoother traffic may not emerge until a sufficiently large proportion of vehicles are equipped.

B.2.6 Technology cost analysis (CIAM)

This process considers the costs of fitting and using the vehicle technologies. Two top level categories of cost are considered:

- Fitment costs: a one-off cost added to the cost of designing and manufacturing the vehicle. This cost is calculated by multiplying the unit cost of each technology by the number of new vehicles introduced each year.
- Annual operational costs: maintenance, which the user pays for regularly, and repair costs which arise in case of collisions or damage to the vehicle (e.g. camera recalibration after windscreen damage). This cost is calculated by multiplying the annual cost per vehicle by the number of vehicles fitted with the technology in the fleet.

The cost impacts are considered as changes in costs (increases or decreases) that are a consequence of the technology, i.e., unlike with the other impacts considered, there is no baseline cost and no equivalent to the technology effectiveness factors. Instead, tables of unit costs (per vehicle) for fitment and annual costs for each technology are multiplied by the numbers of vehicles to reach a total annual user cost.

The calculation considers two other factors:

1. Cost reductions that occur because some of the technologies involve shared sensors, so the combined cost of two together is less than the sum of each fitted individually. A ‘cost interaction’ table is compiled that provides cost reductions, as percentages, that should be applied for specified combinations of technologies.
2. Cost reductions over time arising from economies of scale as manufacturers increase production rates and products become standard parts of the build. This is done by providing a table of annual scaling factors to adjust future costs to reflect a user-specified economies of scale curve.

Fitment costs apply once only and are counted in the year in which a vehicle enters the fleet. Operational costs apply to every fitted vehicle for every year in which it remains in the fleet. Total annual cost differences are calculated for each category, by vehicle category, for voluntary and mandatory scenarios; and the difference between the two becomes the input to the economic analysis.

Summary of process:

- Inputs:
  - Fitment and maintenance/repair unit cost estimates
  - The total number of newly equipped vehicles introduced each year, calculated from previous CIAM step

  - The stock of equipped vehicles, i.e. the annual fitment rate × total number of vehicles in the fleet, calculated from previous CIAM step
- Outputs (which serve as inputs for EAM):
  - Tables of annual fitment and maintenance/repair costs segmented by vehicle category
- Limitations:
  - None

B.2.7 Economic analysis (EAM)

The purpose of EAM is to calculate a series of economic indicators based on the impacts calculated by CIAM. The model was designed to conform to best practice and guidance set out in both the Government's TAG and Green Book. The economic indicators output by the model are generally provided as both a total value and segmented by vehicle category, and calculated for three sensitivity scenarios (Central Estimate, Optimistic, Pessimistic). The indicators include:

- Present value costs
- Present value benefits
- Benefit-cost ratio (BCR)
- Net present value (NPV)
- Equivalent annual net direct cost to business (EANDCB)

The model inputs include the casualty, collision, fuel/energy, emissions, journey time, and cost impacts calculated by CIAM as described in the preceding sections. In addition, the model draws on a series of parameters for monetisation and other steps as described below. The parameters applied and their sources are summarised in Table 32. The specific values can be found integrated in EAM.

Table 32: Source information for parameters applied in EAM CBA model, TAG data book version used: v1.21, May 2023 (Department for Transport, 2023)

Parameter	Source
Casualties prevented (killed) £ / casualty	TAG data book COBALT 1
Casualties prevented (serious) £ / casualty	TAG data book COBALT 1
Casualties prevented (slight) £ / casualty	TAG data book COBALT 1
Collisions prevented (killed) £ / collision	TAG data book COBALT 1
Collisions prevented (serious) £ / collision	TAG data book COBALT 1
Collisions prevented (slight) £ / collision	TAG data book COBALT 1
Collisions prevented (damage-only) £ / collision	TAG data book COBALT 1
CO2 £ / kt	TAG data book A3.4
NOx £ / t	TAG data book A3.2.1
PM £ / t	TAG data book A3.2.1
Diesel £ / thousand litres pvt	TAG data book A1.3.7
Petrol £ / thousand litres pvt	TAG data book A1.3.7
Electricity £ /million kWh pvt	TAG data book A1.3.7
Journey time difference million hours	TAG data book M2.1
Proportion of business vehicles vs private vehicles	https://www.racfoundation.org
Indirect tax revenue	TAG Unit A1.1–- Cost Benefit Analysis (publishing.service.gov.uk)
VAT: Electricity	https://www.gov.uk/government/collections/rates-and-allowances-hm-revenue-and-customs#vat
VAT: Petrol, Diesel	Fuel Duty–- GOV.UK (www.gov.uk)
Duty: Fuel and Energy	Fuel Duty–- GOV.UK (www.gov.uk)
GDP Deflator	TAG data book Annual Parameters
Inflation series	TAG data book Annual Parameters

To calculate the economic indicators, the following steps are performed by the EAM CBA model:

1. Monetise year-on-year benefits
2. Convert costs and benefits to present values (discounting)
3. Aggregate costs and benefits over appraisal period
4. Calculate indirect taxation for fuel and energy

5. Calculate VAT lost for fuel and energy, including: technology fitment costs (total, borne by vehicle manufacturers), maintenance/repair costs (only the part for business-owned vehicles), and fuel/energy costs (only the part borne by business users)
6. Calculate net direct cost to business
7. Calculate economic indicators:
    - BCR = present value benefits / present value costs
    - NPV = present value benefits – present value costs
    - EANDCB = net direct cost to business / (((1 + discount rate) / discount rate) x (1 – (1 / (1 + discount rate)^time period)))

Appendix C Input data for impact modelling

This appendix concerns the data that was input into the Clustered Impact Appraisal Model (CIAM) to calculate impacts for the present study. The sections below give an overview of data sources used, describe data extraction and calculation methods (e.g. for casualty baselines) and summarise resulting input values.

Preceding Appendix B describes the structure of the models developed to quantify and monetise the primary impacts and the calculation methods implemented. Subsequent Appendix D provides summary tables of results calculated by CIAM and the Economic Appraisal Model (EAM) based on the input data described in this appendix.

C.1 General approach for data collection

To calculate the impacts arising from mandatory technology implementation, the data categories presented in Table 33 were required as inputs to CIAM (see Appendix B). The methods employed to gather the data included stakeholder consultation, rapid evidence assessment, data acquisition from the DfT, calculations, expert estimates and STATS19 collision data analysis.

Table 33: Overview of input data categories used for impact modelling, their purpose and the methods employed to gather them

Data category	Main purpose	Method
Vehicle fleet numbers	Fleet dispersion and cost calculations	DfT provided
Vehicle new sales	Fleet dispersion and cost calculations	DfT provided
Vehicle kilometres per year	Emissions calculations	DfT provided
Voluntary technology adoption rates	Fleet dispersion calculations of business-as-usual case	Stakeholder consultation, expert estimates
Casualty baseline	Casualties prevented calculations	Collision data analysis, calculations
Casualty target populations	Casualties prevented calculations	Collision data analysis
Collision constants	Collisions prevented calculations from casualty prevented, collision distribution by road type	Collision data analysis, TAG data book
Technology effectiveness casualties	Casualties prevented calculations	Rapid evidence assessment, EU CBA
Emissions baseline CO2	Emissions saved calculations	DfT provided
Emissions technology effectiveness CO2	Emissions and fuel saved calculations	Rapid evidence assessment
Emissions baseline NOx	Emissions saved calculations	DfT provided

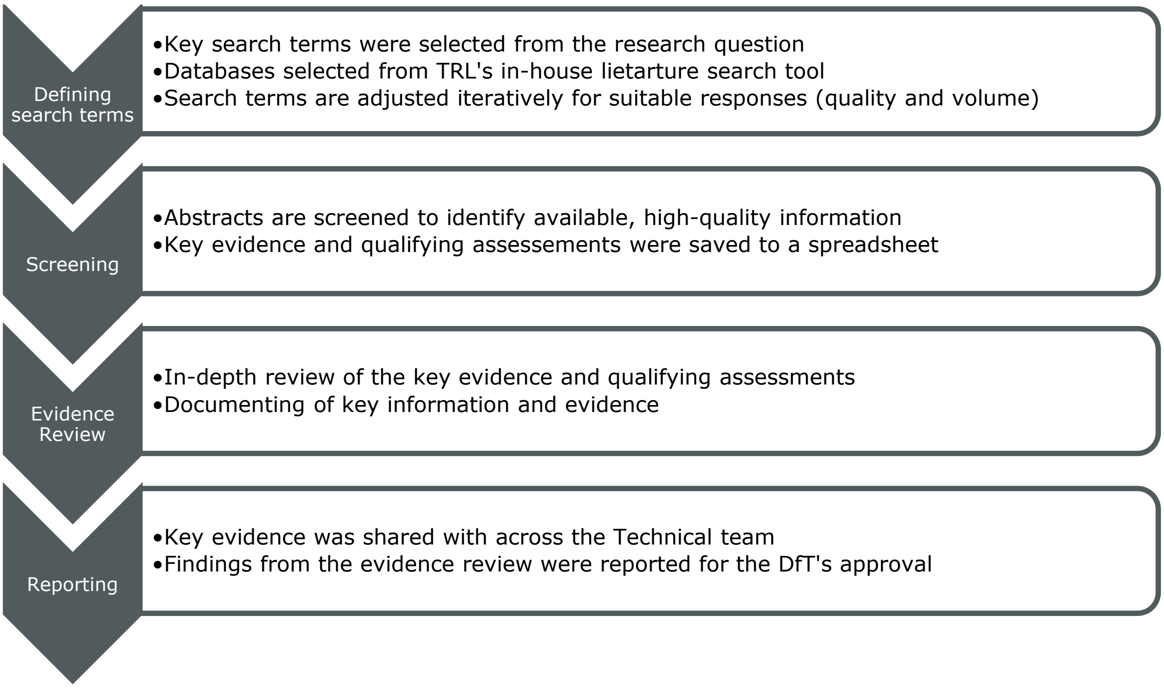
Data category	Main purpose	Method
Emissions technology effectiveness NOx	Emissions saved calculations	Rapid evidence assessment
Emissions baseline PM tailpipe	Emissions saved calculations	DfT provided
Emission factors PM	Emissions saved calculations: PM from tyre- and brake-wear	Rapid evidence assessment, calculations
Emissions technology effectiveness PM	Emissions saved calculations	Rapid evidence assessment
Fuel and electricity consumption baseline	Electricity and fuel saved calculations	DfT provided
Electricity consumption technology effectiveness	Electricity saved calculations	Rapid evidence assessment
Journey time baseline	Journey time saved calculations	DfT provided
Journey time technology effectiveness	Journey time saved calculations	Rapid evidence assessment
Technology fitment costs	Cost calculations: One-off fitment costs	Stakeholder consultation, EU CBA, calculations
Technology maintenance and repair costs	Cost calculations: Ongoing annual costs	Stakeholder consultation, calculations
Technology cost overlaps	Cost calculations: Reductions when technologies share sensors	Calculations, expert estimates
Technology cost economies of scale	Cost calculations: Reductions over time with improved design and production	Expert estimates

Further detail on the methods employed for data gathering and the sources and values chosen for key inputs are provided in the following sections.

C.2 Rapid evidence assessment

C.2.1 Method

A rapid evidence assessment was performed to review the literature sources most likely to yield suitable inputs for the cost-benefit model. This review process prioritised efficiency whereby evidence from previous work (Seidl M, 2017)) is used where appropriate and only more recent sources, sources specific to GB or UK conditions and sources for aspects not previously studied were included.



TRL's in-house literature search tool was used to conduct concise and accurate reviews across multiple databases simultaneously. Suitable search terms were selected based on the research question and terminology was broadened to account for safety technologies with multiple accepted names whenever necessary (e.g. intelligent speed adaptation and intelligent speed assistance). The main resources for the literature search were the following webpages:

- Science Direct
- Google Scholar
- Google search engine

C.2.2 Technology effectiveness (safety)

<u>What is the effectiveness of the safety technologies at preventing fatal, serious and slight casualties/collisions or damage-only collisions?</u>

Note that this review only considered studies that were not previously considered for selection in the context of the EU cost-benefit study (Seidl M, 2017) or were based on GB- or UK-specific data. Critical appraisal of the new sources identified was performed in comparison to the sources used for the EU assessment in order to decide on effectiveness estimates to apply (see Appendix C.6.1).

Advanced distraction warning (ADW): An FKA/TRL study reviewed the technical upgrades necessary to the advanced driver distraction warning systems and concluded that a consensus on the appropriate metrics to consistently measure the performance and ultimately the effectiveness and efficiency of ADW systems still needs to be found (Laxton V, 2022). ADW is a relatively immature technology so high-quality assessments of the effectiveness for this type of safety feature are not yet available.

Alcohol interlock facilitation (AIF): No additional studies have been identified.

Blind spot information (BSI): No additional studies have been identified.

Drowsiness and attention warning (DAW): As part of the DRIVEN consortium, TRL performed a case-by-case analysis of RAIDS in-depth collision data to estimate the effectiveness of DAW systems (Ellis, Hammond, Kent, & Appleby, 2018). It assessed 67 cases (mostly cars but also involving 8 HGVs, 5 vans, 2 motorcycles, 1 motorbike and 1 bus) involving fatigue as a contributory factor to assess whether drowsiness would have been picked up by the system, whether the driver would have been likely to respond to a signal, and whether the accident could have been avoided. The study concluded an effectiveness estimate of 48% for DAW systems in preventing collisions involving fatigue.

Direct vision (DIV): No additional studies have been identified.

Emergency braking for cyclists (EBC): A French study assessed the effectiveness of autonomous emergency braking (AEB) systems in car-to-cyclist frontal collisions by simulating their effects, on a representative target population of real-world accidents. AEB–cyclist effectiveness was shown to range from 35% to 59% in fatalities, 14% to 54% in severe injuries, and 11% to 42% in slight injuries (Chajmowicz H, 2019).

A 2020 study combines results from counterfactual simulations and real-world testing to quantify the safety benefit of ADAS for VRU protection which concluded that "braking only" function could potentially reduce car-to-cyclist fatalities by 61%–71% (Kovaceva J, 2020).

A 2023 retrospective study from the USA for a single system implementation (Subaru EyeSight) found a 29% reduction in parallel crash rates and 9% in overall bicycle crash rates (Cicchino, Effects of a bicyclist detection system on police-reported bicycle crashes, 2023). With regard to the low effectiveness found for the overall crash rate it needs to be considered that the system assessed has limited capability to prevent collisions with cyclists moving in perpendicular direction to the subject vehicle and is therefore not equivalent to EU specifications.

A retrospective real-world study based on Swedish data and investigating technologies with a system description closely matching the EU specification found a statistically significant 21% reduction of vehicle-bicycle injury crashes (Kullgren, Amin, & Tingvall, 2023).

Emergency braking for pedestrians (EBP): (Haus S, 2019) estimated based on simulation that automatic emergency braking (AEB) that detects pedestrians could potentially reduce US pedestrian fatality risk by 84%–87% and serious injury risk by 83%–87% when optimally designed.

(Cicchino, Effects of automatic emergency braking systems on pedestrian crash risk, 2022) found in a retrospective real-world study based on US data that the effectiveness of pedestrian-detecting AEB can be associated with reductions of 25%–27% in the risk of a pedestrian crash and 29%–30% in the risk of a pedestrian injury crash. This is likely to be a conservative estimate because there is no evidence that the system is preventing pedestrian crashes under challenging characteristics (dark conditions without street lighting, at speed limits greater than 50 mph or AEB-equipped vehicle turning). Effectiveness estimates increased in crashes without these challenges with reductions of 45%–49% in the risk of a pedestrian crash and 47%–50% in the risk of a pedestrian injury crash associated with the system.

A retrospective real-world study based on Swedish data and investigating technologies with a system description closely matching the EU specification found an 8% reduction of vehicle-pedestrian injury crashes; however, these results were not statistically significant (Kullgren, Amin, & Tingvall, 2023)**.**

Emergency braking for vehicles (EBV): A retrospective, real-world study based on US data found the following statistically significant effectiveness for forward collision warning (FCW) and automatic emergency braking (AEB) systems (Cicchino, Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates, 2017): low-speed AEB alone, and FCW with AEB reduced rear-end striking crash involvement rates by 43% and 50%, respectively. Rates of rear-end striking crash involvements with injuries were reduced by 45% and 56%, respectively. The EU regulation requires a warning and automatic braking, so the rates for FCW with AEB are most applicable.

Leslie studied the field effectiveness of General Motors advanced driver assistance and headlighting systems in the USA (Leslie A, 2021). Overall AEB effectiveness was found at 40%.

Event data recorder (EDR): No additional studies have been identified.

Emergency lane keeping (ELK): No additional studies have been identified.

Emergency stop signal (ESS): No additional studies have been identified.

Frontal full-width impact (FFI): No additional studies have been identified.

Frontal off-set impact (FOI): Farmer conducted a retrospective, real-world study on the effectiveness of US IIHS frontal offset crash tests in cars, minivans, SUVs and pickup trucks (Farmer, 2005). The IIHS test protocol is higher energy (64 km/h) than the test applicable in the EU (UN R94, 56 km/h) and the connection between IIHS ratings (poor, marginal, acceptable, good) and UN R94 results (pass/fail) are not exact. Most appropriate appears the application of effectiveness estimates for vehicles in head-on crashes comparing vehicles in the medial group (i.e. either marginal or acceptable rating in IIHS test), to represent a pass of the UN R94 test, with vehicles having a poor IIHS test result, to represent a fail of the UN R94 test. The effectiveness in fatal crashes was found to be 45%.

Intelligent speed assistance (ISA): (Lai, Carsten, & Tate, 2012) performed data analysis of a large, UK-based on-road trial of ISA technology to determine the expected safety effects of ISA for the UK. The study analysed three technology implementations:

- Advisory (i.e. warning only)
- Voluntary (intervening but overridable)
- Mandatory (intervening not overridable)

The EU regulation allows both advisory and voluntary system implementations and it is expected that a mix will appear in the fleet. The study estimates the proportion of all UK road collisions that would be prevented at full fleet adoption at 2.7% for advisory systems and 12.0% for voluntary systems. (Carsten O L. F., 2008), the study on which the safety results quoted by (Lai, Carsten, & Tate, 2012) are based, breaks these down further by collision severity level and reports effectiveness values as shown in Table 34.

Table 34: ISA effectiveness at reducing overall UK road collisions at full fleet adoption by system implementation and collision severity (Carsten O L. F., 2008)

	Fatal collisions	Serious collisions	Slight collisions
Advisory system	9%	4%	2%
Voluntary system	25%	19%	10%

The UK trial data on which the above studies are based was collected in 2004 and should be adapted to reflect potential changes in baseline speed limit compliance over the last two decades.

Moving off information (MOI): No additional studies have been identified.

Pole side impact (PSI): No additional studies have been identified.

Pedestrian windscreen impact (PWI): No additional studies have been identified.

Reversing motion awareness (RMA): No additional studies have been identified.

Tyre pressure monitoring (TPM): No additional studies have been identified.

C.2.3 Target populations (safety)

What proportion of GB road collisions are fully or partially caused by driver fatigue or driver distraction?

The size of the target populations on which the safety technologies under consideration can act in GB are determined from STATS19 collision data (see Appendix C.2.3). These numbers will be sufficiently accurate for most technologies, however specifically for ADW and DAW the number of casualties for which the technology could help is assumed to be substantially under-reported in STATS19 because they are based on contributory factors (driver distraction and driver fatigue, respectively) which are difficult to determine by police after a crash occurred. Therefore, it is proposed to uplift the target population sizes extracted from STATS19 by fixed factors to represent the real-world prevalence of fatigue and distraction in collisions. The uplift factors will be determined from the real-world prevalence reported in studies compared to the prevalence in the STATS19 sample.

Advanced distraction warning (ADW): In-depth research on the real-world prevalence of distraction in GB collisions could not be identified. For Europe, the European Commission quotes distraction being a contributory factor in 10% to 30% of road collisions (European Commission, 2020)**.**

Drowsiness and attention warning (DAW): Research found that fatigue can be estimated to be a contributory factor in 20% of UK road collisions (Jackson, et al., 2011).

C.2.4 Technology effectiveness and wider impacts (environmental impacts)

This section reports the literature on environmental aspects, including emissions. Please refer to Appendix C.6.2 for details on the technology effectiveness values selected.

What is the effect of TPM (or correct pressure vs. low pressure) on fuel consumption/CO_2 emissions in trucks, buses/coaches and vans? What is the effect of low tyre pressure on tyre wear?

The IEEE published a paper which explores the influence of tyre pressure on safety and energy/fuel consumption (Marton Z, 2014). They reported that small tyre underinflation (17%) can increase fuel consumption by 2%.

The Environmental Protection Agency and NHTSA estimated that underinflated tyres (10 psi or more) can decrease fuel economy by up to 1% for medium and heavy-duty vehicles (US EPA & NHTSA, 2016).

(Thomas J, 2014) found that a decrease in tyre pressure beyond standard tyre pressure decreased the fuel efficiency and increases the emission rate. Fuel economy decreased by 0.3% with every 1 psi reduction in tire pressure.

(Toma, 2018) concludes that with a drop in pressure in truck tyres by 0.02 mPa (3 psi), fuel consumption increased by 1.5%.

(Szczucka-lasota B, 2019) found that tyre pressure has the greatest impact on the reduction of fuel consumption compared to other variables (e.g. vehicle weight, brake usage, average speed). With the pressure increased by 0.1 mPa (14 PSI), fuel consumption decreases by an average of 5.15 l / 100 km.

Goodyear tires carried out a tyre pressure monitoring operation in the Netherlands examining 400 wheels of trucks and trailers (Pölös, 2022). The results show that 75% of checked HGVs and trailers had at least one underinflated tyre. The pressure in the tyres was on average 12.8% lower than it should have been.

A tyre that is not properly inflated (17% underinflation) can have a reduced lifespan by 20% or 25% compared to a tyre that is inflated correctly (Volvo Trucks, 2020), (Egaji O A, 2019), (Marton Z, 2014).

It can be concluded that there is a significant prevalence of under-inflation in the UK, which leads to significant increase in tyre wear, with reductions in tyre lifetime of up to 25%, and hence emissions of tyre particles to the air and water courses. No direct quantitative evidence was found of the extent to which TPM would reduce this level of wear. To obtain a technical effectiveness factor for the impacts model it is therefore necessary to make some appropriate estimates of the prevalence of under-inflation, the percentage change this has on fuel consumption and the extent to which TPM users will respond to warnings by correcting their tyre pressure.

What is the effect of TPM in vans, trucks, buses/coaches on vehicle breakdown rates?

No evidence was found to answer this research question.

What is the effect of ISA on fuel consumption and greenhouse gas emissions?

It is well known that there is a strong relationship between fuel consumption and speed, and average speed can be used as a predictor of fuel consumption for many purposes, for example the equation and parameters used in the TAG Data Book A1.3.8. On this relationship, speed reduction would be expected to reduce fuel consumption on high-speed roads but increase it on low-speed roads. However, by limiting the maximum speeds, ISA is altering the distribution of speeds, not just the average, and could affect driving style (i.e. braking and acceleration), resulting in changes in fuel consumption that differ from predications made just by considering average speed. For this reason, the evidence review sought results from studies specifically focused on the effects of ISA, or real-world data from speed reduction measures that might similarly limit the top speeds in the distribution.

To date only a small number of ISA studies have been undertaken in the UK.

(Carsten O L. F., 2008) analysed data from the changed in speed distribution observed in the real-world UK ISA trials, together with traffic network simulation. This work identified small (~3%) fuel consumption savings on high-speed roads, but small increases (also ~3%) on urban roads. Elsewhere no difference was found. (Lai, Carsten, & Tate, 2012) undertook further analysis of the UK ISA data as part of a cost-benefit analysis study. The predicted CO_2 savings on 70 mph roads from voluntary and mandatory ISA are 3.4% and 5.8% respectively. Larger vehicles and lower speed roads were not included in this analysis, because the impacts were considered to be 'small and variable'.

(Ryan, 2019) reviewed ISA studies from across the world. Quite a wide range of results were found, the majority reporting fuel savings, of up to 11%, although the majority were below 5%, and the author concludes that the introduction of ISA "will result in reductions in fuel consumption and emissions". The author also hypothesises that fuel savings will improve over time because manufacturers will optimise their vehicle design for lower speeds under ISA.

Is there evidence that ISA affects driving behaviour, in particular harsh braking?

No studies or papers were found that conducted a detailed study in this area, the focus appeared to be on whether ISA systems were able to apply the vehicle brakes. There was a study conducted by Transport for London (TfL) after they had fitted ISA to part of their vehicle fleet (mostly cars, small utility vehicles and panel vans) (Dodd, 2022). This reported that after a period of assessment of TfL's vehicle fleet fitted with ISA, no increase in harsh braking events were seen with this system fitted.

Another paper (Paine, 2009) suggests that harsh braking would be reduced with the introduction of ISA systems, however, does not explicitly mention this.

Many reports, such as (Doecke, Raftery, Elsegood, & Mackenzie, 2021), discuss the positive impact ISA will have on incidents and collisions on the road network, however, assume that the same level of braking would be applied.

In a review of global ISA studies, Ryan (Ryan, 2019)identifies a range of observed changes in driver behaviour, some positive and some negative in terms of their likely effect on fuel consumption. No firm conclusion could be drawn from the available evidence on whether there would be significant changes in the use of brakes, or how this might change in the longer term as drivers become accustomed to driving with ISA.

It can be concluded that there is insufficient evidence to draw any firm conclusions about changes in harsh braking or acceleration as a result of ISA. While this might still be a factor in observed changes in fuel consumption, it is not possible to isolate it from overall speed changes. No quantitative impacts on tyre or brake wear can therefore be attributed to braking behaviour changes caused by ISA with the available evidence.

What is the evidence on water pollution from tyre particles and other vehicle-related pollutants entering the water system?

It is estimated that the average amount of microplastics released by wear and tear of tyres each year in the United Kingdom, Germany, and Japan is around 63 kilotonnes, 125 kilotonnes, and 240 kilotonnes, respectively (Kole P J, 2017). The authors state that tyre wear and tear particles emitted on roads can be dispersed in the environment via different pathways. Small particles are typically emitted into the air and prone to air dispersal, whereas large particles will get deposited on the road surface where some parts will get trapped and other parts will be transported by rainwater runoff into soils, sewers and/or surface waters.

What proportion of the microplastics reach surface waters depends on the local sewage system and information specific to the UK could not be identified. However, (Kole P J, 2017) cite findings from the Netherlands which show that 12% ultimately reach surface waters.

It can be concluded that any technology that affects the rate of tyre wear will affect contamination as well as concentrations of airborne particles. No definite method for quantifying the impacts on water were found, which is why this impact will only be considered qualitatively in this CBA.

What is the evidence on the relationship between noise level and speed limit compliance?

No directly applicable evidence was found relating to speed limit compliance and noise level but there is a documented, direct relationship between the amount of noise generated from a vehicle and the speed at which that vehicle is travelling. Data from the USA shows the different noise levels generated from cars, medium lorries and large lorries, a summary at typical speeds has been provided in Table 35.

Table 35: Noise generated from vehicles at different speeds; noise at 50 ft in dB (nonoise.org, 2023)

Speed (mph)	Car (dB)	Medium truck (dB)	Large truck (dB)
30	62	73	80
40	67	78	83
50	70	81	85
60	73	84	87
70	76	86	89

It can be seen that raising the speed of a vehicle by 10 mph increases the noise of that vehicle by ca. 3 dB (range of 2 to 5 dB depending on vehicle category and speed band). (nonoise.org, 2023) also mentions that reducing vehicle speed from 40 mph to 30 mph will reduce the noise generated the equivalent amount as removing half the vehicles from the roads.

It can be concluded that significant noise reduction could be achieved at some locations by greater compliance with speed limits due to ISA. The extent of these benefits would depend upon the level of non-compliance at each location and the number of people exposed to that noise. Detailed modelling would therefore be required, using speed distribution data with a very high level of spatial granularity. As such work was outside the scope of the current project, no attempt was made to quantify or monetise noise benefits; however their existence should be noted qualitatively as a potentially important benefit in residential streets that suffer from significant speeding.

What is the evidence on the relationship between harmful emissions and speed limit compliance?

There is a mixed response on the effect of vehicle speed on harmful emissions. (Folgero, Harding, & Benjamin, 2020) explains that engineering simulation models often find that a reduced vehicle speed will have a positive effect on harmful emissions, however, many real-world studies often see little or no improvement.

(Folgero, Harding, & Benjamin, 2020) goes on to explain that the effect of speed on harmful emissions is very difficult to predict as it depends greatly on the behavioural responses of the drivers as well as the engineering relationship between speed and emissions of the vehicle fleet on the roads. A study was conducted by (Folgero, Harding, & Benjamin, 2020) in Oslo in Norway which found no improvement in air pollution as a result in speed reduction from 80 km/h to 60 km/h. They found that PM2.5 and NOx emissions from heavy lorries increased when speed fell below 55 km/h. They also noticed the highest emissions of HC, CO, and NOx from light duty vehicles when traffic is caused to accelerate and decelerate (for example, from free-flowing to congestion and congestion to free-flowing).

(Folgero, Harding, & Benjamin, 2020) also summarises many similar studies investigating the relationship between harmful emissions and speed of vehicles taken place in other parts of the world. The researched 13 studies from across Europe and USA, 7 of which found improvements in either NOx or PM as a result of speed reduction and 6 of which found an increase of emissions.

(Gressai, Varga, Tettamanti, & Varga, 2021) also found similar mixed results in emission reduction and explain that each city would need to be carefully assessed to determine the best method of reducing emissions.

Focusing on ISA, (Lai, Carsten, & Tate, 2012) concluded that emissions impacts were “negligible”, while a literature review of a number of ISA studies (Ryan, 2019) found some examples of reduced NOx emissions, using supportive ISA, but overall no significant impacts were found.

It can be concluded that no definitive relationship between speed enforcement and NOx or tailpipe PM emissions can be found in the reviewed evidence. The impacts can be positive or negative, depending on the effects on traffic flow.

C.2.5 Technology effectiveness (journey times)

This section reports the literature on journey times. Please refer to Appendix C.6.2.1 for details on the technology effectiveness values selected.

What is the evidence for impacts on traffic flow/congestion from speed limiting or other measures that affect driver behaviour?

A TfL study on vehicles retrofit with ISA (see Appendix C.2.4) found that the average distance travelled and average journey time taken for each trip was largely unaffected by the fitment of ISA (Dodd, 2022). This indicates that limiting the speed of individual vehicles did not impact on journey time on trips on the Greater London road network.

(Gressai, Varga, Tettamanti, & Varga, 2021) mentions several different measures that aim to reduce congestion including parking regulations, restricting traffic movement, public transport priority, traffic management measures, overloaded vehicle detection. However, the focus of their paper was on speed limit reduction.

Much like the effect of speed on harmful emissions, the effect on congestion is very dependent on the city. This paper looked into many international studies which found mixed results on the effect of congestion as a result of speed reduction; however, conclusive evidence was found in the relationship between traffic accidents and vehicle speed.

They conducted their own study, looking into the effect of vehicle speed on congestion in Nagykörút in Hungary on urban roads and urban motor ways. This study found that the overall road capacity was largely unchanged when speed limits were changed between 30, 40 and 50 km/h on urban roads and 50, 60 and 70 km/h on urban motorways. They also assessed the number of stops by vehicles and found that more stops were made at the lower speeds on both urban roads and urban motorways.

A study by (Papageorgiou, Papamichail, & Kosmatopoulos, 2008) also found no clear evidence of improved traffic flow as a result of controlled speed limits, however, the safety benefits were clear.

(Soriguera, Martinez, Sala, & Menendez, 2017) also explains the relationship between vehicle speed and road occupancy. They explain that to achieve the same flow at lower speeds, higher density of vehicles is required. This results in drivers leaving smaller gaps at lower speeds to achieve the same flow rate. In a literature review on the impacts of ISA (Ryan, 2019) the author found mixed results, which several examples of increased travel times with ISA (for example 2.6% at peak times to 6.4% off-peak); however, others reporting better traffic flow and journey time reliability.

From this review the impact of ISA on journey times cannot be concluded definitively because different studies indicate different trends. ISA may increase journey times overall, but also offers potential for improved traffic flow and improved journey time reliability.

C.2.6 Fleet fitment rates

What percentage of the GB or UK fleet is currently equipped with the safety technologies under consideration? Is there forecast data on future fitment rates?

To date, not much research has been published on fleet fitment rates of specific safety systems in the UK or GB.

The uptake of ADAS on commercial fleets appears to be rising. (Wright, 2022) states in his article on ADAS features for UK fleets that the most popular ADAS features fitted to company cars were collision avoidance (38%), automatic emergency braking (37%), driver fatigue warning (35%), lane departure warning (34%), pedestrian detection system (32%), adaptive cruise control (25%) and automatic parking system (14%).

Analysis from (McDonald, 2022) found that an average UK vehicle has 8 safety features. It also found that 64% of the vehicles across Europe were equipped with one of the core safety features forward collision mitigation (such as emergency braking), blind spot warning, and rear collision warning.

More information could be found on the availability of some ADAS features on new vehicles:

Emergency braking systems: Information was not found on the specific types of emergency braking systems. (Autovista24, 2018) notes that the Society of Motor Manufacturers and Traders research shows that in 2018, emergency braking systems are available on 53.1% of all new cars with 25% fitted as standard in the UK. (McDonald, 2022) also states more recently that 70% of new cars in the UK have emergency braking systems fitted as standard.

Lane departure warning: (Glasgow) states that in 2017 6% of new vehicles for sale in the UK are fitted with lane departure warning systems in the UK.

Intelligent speed assistance (ISA): There is little data showing the uptake of ISA in the UK; however, (RoadSafe, 2022) mention a statistic from Fleet World that 73% of UK motorists back using in-car technology that would help ensure they stick to the speed limit.

Parking assistance: (Blackmore, 2018) mentions that in 2018, 58.8% of new cars in the UK include parking assistance technology such as cameras and sensors as standard or as an option.

On the topic of GB or UK fleet fitment, it can be concluded that the published information is not sufficient to fully inform this cost-benefit study. Input on fitment rates (current and future expected without regulation) will be sought from stakeholders and estimates will be established from stakeholder contributions and previous estimates for the EU CBA.

C.2.7 Costs

<u>What is the fitment cost to a vehicle manufacturer to equip new vehicles with the safety technologies under consideration?</u>

Published evidence on fitment costs was scarce, with ISA being the only safety technology that was found to have a unit cost in relevant research literature. A 2006 joint study by the University of Leeds and MIRA estimated the unit cost for ISA to range from £300 - £1300, shown in Table 36 (Jamson S, 2006) and the 2008 ISA-UK study predicted that ISA would cost £293 and £110 per unit by the years 2010 and 2020 respectively, as shown in Table 37 (Carsten O F. M., 2008).

Table 36: Unit cost ranges for ISA system (Jamson S, 2006)

	Advisory ISA	Intervening ISA
Basic	£300 – £400	n/a
More advanced	£600 – £800	£1,100 – £1,300

Table 37: Total expected cost of in-vehicle ISA equipment (year 2006 pounds) (Carsten O F. M., 2008)

Vehicles	Fitment	ISA category	2010	2020	2030 onwards
Light vehicles	New	Advisory	£220	£110	£110
		Voluntary/Mandatory	£820	£560	£560
Heavy vehicles	New	Advisory	£220	£110	£110
		Voluntary/Mandatory	£1,220	£860	£860

TRL's EU cost-benefit study assumed that a camera-based ISA system with sensors shared with several systems such as EBV, EBP, EBC, ELK would cost in the range of €47–62 per vehicle (this is the cost component for only the ISA-part of the combined system). A 2018 study pushed-back against this cost estimate because it assumed that by 2010 all new vehicles will come with a satellite navigation system as standard. Equipment rate for new cars in Germany in 2017, only 60% of the new vehicles are equipped with navigation system. Furthermore, the BCR calculation assumes that speed limit data incorporated into digital road maps would be available on a pan-European basis by 2010, which was not the case by 2018 (Unger T, 2018).

It can be concluded that for most systems no published fitment cost data is available and the published cost estimates available for ISA are outdated and do not reflect more recent changes in technology such as sensor sharing with other systems. Input on fitment costs will be sought from stakeholders and up-to-date cost estimates will be established from stakeholder contributions and previous cost estimates for the EU CBA.

What is the lifetime cost to the vehicle owner of the safety technologies being fitted to their vehicle (e.g. maintenance and updating of systems, replacement of sensors after collision damage, windscreen change requiring re-calibration)?

In 2017 Thatcham reported that the average automobile repair bill had increased 32% over the last three years. This increase had been driven by "the reparability of parts such as headlamps, increasing complexity of vehicle materials and technology and the rising cost of spare parts, influenced to some extent by currency fluctuations." ADAS was one of the contributing factors along with complex vehicle structures and smart technologies also impacting the cost of repair (Thatcham Research, 2017).

In 2018, the AAA conducted a small study into the repair costs ADAS cameras and sensors featured on three popular American passenger vehicles. The following list of the repair costs for damaged ADAS cameras and sensors was published (American Automobile Association, Inc., 2018):

- Front radar sensors used with AEB systems: $900 to $1300
- Rear radar sensors used with blind spot monitoring systems: $850 to $2,050
- Front camera sensors used for AEB and LKA: $850 to $1,900

- Windscreen replacement for vehicle equipped with AEB and LKA systems:
  - OEM glass: $1,300 to $1,650
  - Aftermarket glass: $1,200 to $1,600

A Dutch industry organisation for car dealerships and garages, BOVAG, conducted an assessment of the monetary effects from different road collision profiles as a consequence of ADAS. This study found that the cost of repairs will increase, putting pressure on the profit margins of the repair and maintenance industry. Although in the long term, ADAS has the potential to decrease vehicle repair activities thanks to the following four types of ADAS:

- Automatic Emergency Braking
- Lane Change Assist / Blind Spot monitoring
- Lane Keeping System
- Parking Assist

BOVAG calculated that, in a realistic scenario (in terms of market penetration), these four systems together will lead to a 23% reduction of damage repair volumes. Corrected for increased prices for spare parts and calibration activities, the revenue of damage repair garages is expected to decrease by ca. 9% until 2030 (BOVAG, 2019).

It can be concluded that no immediately suitable basis for cost estimates regarding the maintenance of systems is available in published literature. Input on maintenance costs will be sought from stakeholders. Evidence for the impact on repair costs indicates that individual repairs will increase in effort and cost; however, a wholistic assessment indicates that the collision-prevention effect of ADAS can likely overcompensate this and thereby reduce overall repair volume.

What is the effect of reduced collisions or increased ADAS fitment on vehicle insurance costs?

No publicly available evidence was identified that allowed to determine how insurance premiums were affected in the past or could be affected in the future. Effects on insurance premiums will therefore not be included as a quantitative impact in this study.

C.2.8 Other topics

What is the current rate of collisions where dashcam footage is available?

Our research found no direct information that answered this question, however, (webuyanycar, 2023) conducted a study which found that 20% of motorists in the UK have a dashcam installed. It also found that cars priced at over £15,000 are three times more likely to use a dashcam compared to drivers of cars valued at £1,000.

This question is relevant to estimate potential secondary benefits arising from EDR (access to justice). From this review it can be concluded that the majority (ca. 80%) of the UK car fleet is not equipped with dashcams which could support access to justice after a collision and that the prevalence of dashcams is considerably lower in low-priced cars.

<u>What is relationship between perceived safety and participation in active transport? In particular, is there evidence that lower traffic speeds such as 20 mph can encourage walking and cycling?</u>

There are a large number of case studies where a reduced speed limit has increased the amount of active travel in an area. (20's Plenty for Us, 2023) conducted research which found that active travel increased by 20% when the speed limit is reduced from 30 mph to 20 mph. Their study found that traffic speeds are a major barrier to those choosing to walk or cycle. In Bristol they found that cyclist casualties fell by 40% after a 20 mph speed limit was introduced. (20's Plenty for Us, 2023) also found that in Portsmouth, over 40% of survey respondents said a 20 mph limit has created a safer environment for walking and cycling.

A report by Transport for London (TfL) (TfL, 2022) states that lower speed limits will encourage active transport and have conducted surveys with members of the public which agree with this. However, this report does not include facts from a trial or scheme of the impact on lowering speed limits on active travel.

The National Heart Forum (National Heart Forum, 2010) in a position paper also states the opinion that 20mph speed limits encourage active travel.

This question is relevant for ISA, which could aid the introduction of 20 mph speed limits in relevant areas because adherence to the lower speed limit will be increased by ISA without additional enforcement measures. In conjunction with the evidence identified above, it can be concluded that a secondary benefit of ISA could be an increased participation rate in active transport if more low-speed limits are introduced.

C.3 Technology cost and voluntary fitment data

C.3.1 Stakeholder survey

An online survey was shared with three associations – The Society of Motor Manufacturers and Traders (SMMT), European Association of Automotive Suppliers (CLEPA), and the European Automobile Manufacturers Association (ACEA) who agreed to disseminate the survey link to their members. Additionally, the survey was shared with Euro NCAP. The survey aimed to understand what proportion of the current GB fleet that is already compliant with technical requirements; and what proportion of the GB fleet is expected to be compliant with technical requirements in the near future and later in the absence of mandatory GB regulations. It also aimed to understand the additional cost that would arise for vehicle manufacturers in order to put a vehicle on the GB market that is compliant with the potential regulatory requirements, where it would not be without regulation. The survey was hosted online via Smart Survey and open for a period of five weeks, from 15th May to 16th June.

It received a total of 21 complete responses from 13 original equipment manufacturers (OEMs) and seven organisations that classified themselves as 'other'. 'Other' category responses were varied such as consultant for small manufacturers, importers, second stage or aftermarket suppliers, and distributor. We received fourteen responses for M1 vehicles, four for N1 vehicles, three for M2 and M3 vehicles, and seven for N2 and N3 vehicles (Figure 14).

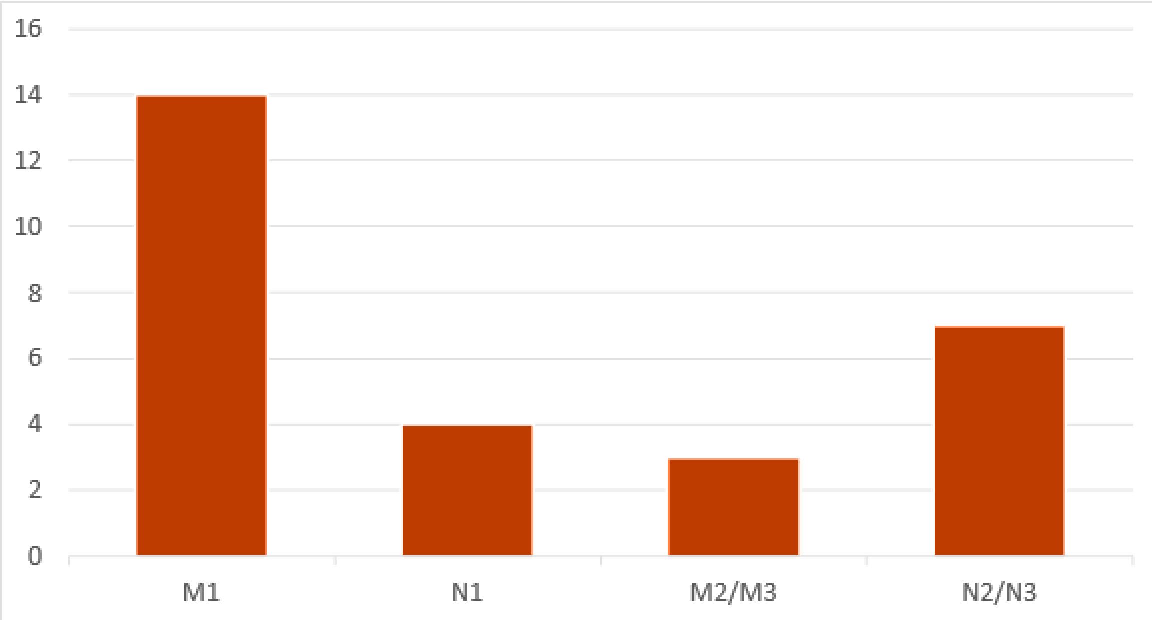


Figure 14: Number of responses provided for each vehicle category

C.3.2 Costs

Fitment and maintenance/repair cost estimates for the technologies considered had to be derived for four vehicle category groups (M1, M2 & M3, N1, N2 & N3) and for three sensitivity parameters (high, medium, low).

C.3.2.1 Technology fitment costs

Cost data to perform estimates was available from the EU CBA (Seidl M, 2017) and the stakeholder consultation, and both sources were used to create the sensitivity ranges.

Stakeholders were guided to provide fitment cost estimates that reflect:

- the total cost to the vehicle manufacturer, including fixed and variable cost of manufacturing and assembly, and overheads for research and development[8] and approval, broken down per vehicle, or
- the price a vehicle manufacturer would pay a Tier 1 supplier for fully manufactured components (‘Tier 1 supplier costs’) with an additional mark-up to reflect costs for

[8] While the technologies are already developed for the EU market and can be implemented, in most cases (except ISA, which would require adaptation to GB road signs or require additional map coverage for GB), without additional research and development to adapt them to GB roads, it is still expected that manufacturers will recoup the previously accrued research and development overheads across all markets where a vehicle is sold, including GB.

acquisition, integration in the vehicle, testing and approval, storage and installation of the components, broken down per vehicle.

A variety of itemised cost estimates (i.e. costs per technology) was received from stakeholders, with more information generally provided for heavy vehicles compared to light vehicles. In general the stakeholder estimates were higher than the values used for the EU CBA; the EU values were therefore used in this study to explore the low sensitivity range for fitment costs: The values were converted to British Pounds and inflated to year 2025 prices and in the following cases also adjusted to reflect changes in technical requirements since the EU CBA was undertaken (see overviews provided in Appendix A.1):

- ADW: Distraction-detection only (no drowsiness)
- BSI: Only nearside detection and only cyclists (no pedestrians)
- DAW: Drowsiness-detection only (no distraction)
- EDR: Changes to E/E architecture and larger EDR storage required to record extended list of data elements
- ELK: No threat detection required
- ISA: Expected map-data to be used in 50% of vehicles (previous assumption was camera-only)
- RMA: Expected that 50% of vehicles would fulfil with detection systems rather than camera (previous assumption was cameras)

The itemised (i.e. per technology) cost estimates received from stakeholders varied widely (sometimes by factors of more than 10) and some estimates were judged as excessively high (the itemised estimates provided ranged up to a cost of £11,600 per car when the vehicle would be equipped with all M1 technologies, which is not plausible considering vehicles in the EU are already being equipped without such substantial retail price increases). The stakeholder data that proved most useful to arrive at reasonable estimates were the expected price increases reported per vehicle. The ranges reported were used to generate the medium and high estimates with using the lower end of the range reported for ‘medium’ and the higher end of the range for ‘high’. The reported price increase was distributed across the individual technologies by applying the average proportions between technologies from the itemised cost estimates received.

The fitment cost estimates derived for this CBA are summarised in Table 38.

C.3.2.2 Technology maintenance and repair costs

Data from stakeholders on this aspect was sparse and there were no previous estimates available from the EU CBA, because this aspect was not considered in the study. In the absence of reliable data, rather than not considering these costs at all, an expert estimate was performed that considered whether a technology required regular maintenance or data updates (e.g. map data updated for ISA) during the vehicle’s life, and whether collisions with minor damages would be expected to make a repair of sensors necessary (e.g. windscreen or bumper damage requiring sensor re-calibration). These considerations were used to derive expected percentages of the initial fitment costs that would be accrued per annum for maintenance and repair. The resulting maintenance/repair cost estimates are summarised in Table 39.

Table 38: Technology cost estimates: Fitment cost for implementation of each technology individually, per vehicle category and per sensitivity range; year 2025 prices in GBP (£)

Vehicle category	Sensitivity range	ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
M1	High	156	10	n/a	49	n/a	246	246	246	33	246	10	82	n/a	211	n/a	246	74	52	n/a
M1	Medium	99	6	n/a	13	n/a	130	130	160	20	163	6	52	n/a	134	n/a	45	22	49	n/a
M1	Low	33	2	n/a	8	n/a	82	82	101	13	103	2	33	n/a	82	n/a	28	14	33	n/a
M2M3	High	297	20	452	388	388	n/a	n/a	n/a	78	n/a	20	n/a	n/a	239	223	n/a	n/a	196	97
M2M3	Medium	233	12	175	28	223	n/a	n/a	n/a	63	n/a	12	n/a	n/a	151	194	n/a	n/a	145	86
M2M3	Low	148	4	111	18	142	n/a	n/a	n/a	40	n/a	4	n/a	n/a	54	142	n/a	n/a	124	55
N1	High	156	10	n/a	49	n/a	246	246	246	33	246	10	82	246	211	n/a	246	74	52	14
N1	Medium	99	6	n/a	13	n/a	130	130	160	20	163	6	52	45	134	n/a	45	22	49	8
N1	Low	33	2	n/a	8	n/a	82	82	101	13	103	2	33	28	82	n/a	28	14	33	5
N2N3	High	331	20	401	187	611	n/a	n/a	n/a	261	n/a	20	n/a	n/a	239	223	n/a	n/a	196	196
N2N3	Medium	233	12	175	28	223	n/a	n/a	n/a	63	n/a	12	n/a	n/a	151	194	n/a	n/a	145	110
N2N3	Low	148	4	111	18	142	n/a	n/a	n/a	40	n/a	4	n/a	n/a	54	142	n/a	n/a	124	69

Table 39: Technology cost estimates: Annual maintenance and repair costs for each technology, per vehicle category and per sensitivity range; year 2025 prices in GBP (£)

Vehicle category	Sensitivity range	ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
M1	High	0.00	0.00	n/a	0.00	n/a	2.46	2.46	2.46	0.00	2.46	0.00	0.00	n/a	6.33	n/a	0.00	0.00	0.52	n/a
M1	Medium	0.00	0.00	n/a	0.00	n/a	1.30	1.30	1.60	0.00	1.63	0.00	0.00	n/a	4.02	n/a	0.00	0.00	0.49	n/a
M1	Low	0.00	0.00	n/a	0.00	n/a	0.82	0.82	1.01	0.00	1.03	0.00	0.00	n/a	2.46	n/a	0.00	0.00	0.33	n/a
M2M3	High	0.00	0.00	4.52	0.00	0.00	n/a	n/a	n/a	0.00	n/a	0.00	n/a	n/a	7.17	2.23	n/a	n/a	1.96	0.00
M2M3	Medium	0.00	0.00	1.75	0.00	0.00	n/a	n/a	n/a	0.00	n/a	0.00	n/a	n/a	4.53	1.94	n/a	n/a	1.45	0.00
M2M3	Low	0.00	0.00	1.11	0.00	0.00	n/a	n/a	n/a	0.00	n/a	0.00	n/a	n/a	1.62	1.42	n/a	n/a	1.24	0.00
N1	High	0.00	0.00	n/a	0.00	n/a	2.46	2.46	2.46	0.00	2.46	0.00	0.00	0.00	6.33	n/a	0.00	0.00	0.52	0.00
N1	Medium	0.00	0.00	n/a	0.00	n/a	1.30	1.30	1.60	0.00	1.63	0.00	0.00	0.00	4.02	n/a	0.00	0.00	0.49	0.00
N1	Low	0.00	0.00	n/a	0.00	n/a	0.82	0.82	1.01	0.00	1.03	0.00	0.00	0.00	2.46	n/a	0.00	0.00	0.33	0.00
N2N3	High	0.00	0.00	4.01	0.00	0.00	n/a	n/a	n/a	0.00	n/a	0.00	n/a	n/a	7.17	2.23	n/a	n/a	1.96	0.00
N2N3	Medium	0.00	0.00	1.75	0.00	0.00	n/a	n/a	n/a	0.00	n/a	0.00	n/a	n/a	4.53	1.94	n/a	n/a	1.45	0.00
N2N3	Low	0.00	0.00	1.11	0.00	0.00	n/a	n/a	n/a	0.00	n/a	0.00	n/a	n/a	1.62	1.42	n/a	n/a	1.24	0.00

C.3.3 Voluntary technology fitment rates

Voluntary technology fitment rates are required to calculate the 'business-as-usual' case for future years to provide the status quo against which the impacts of mandatory implementation are measured. Voluntary fleet dispersion is calculated using S-shaped curves as described in Appendix B.2.1. The required inputs are the first year of technology introduction (at the start of which year, the fleet fitment rate is assumed to be 0%, 'year 1') and the maximum proportion of new vehicles entering the fleet expected to be equipped and the year in which this peak occurs ('year 2'). These estimates were derived for each technology as applicable for the four vehicle category groups considered (M1, M2 & M3, N1, N2 & N3).

Year 1 was defined as either the year of first mandatory introduction in the EU or, where technologies entered the market previously, the year of first fitment to series production vehicles that could be identified from published information.

Year 2 and the proportion of new vehicles that would be equipped in the voluntary scenario were derived from stakeholder responses under additional consideration of future Euro NCAP incentivisation as described in the following paragraphs for light and heavy vehicles.

For light vehicles, the responses received from M1 and N1 vehicle manufacturers indicated that they largely expect to keep their right-hand drive vehicle specification uniform across EU (Ireland) and GB, i.e. would fit the technologies even in absence of GB regulation. This would indicate a voluntary fitment rate of 100% from 2024 or 2026 onward (depending on EU GSR introduction date of each technology). This indicated willingness to fit technologies voluntarily was accepted as a basis; however, the maximum estimated voluntary fitment rate was capped at a slightly lower level to reflect future uncertainty on factors such as changes to manufacturer's purchase pricing strategies in light of increasing competition on the market, unknown willingness of future market entrants to fit technologies, temporary supply shortages of components, or the introduction of vehicle pricing models where active safety technologies (such as ELK, ISA or RMA) remain latent on a vehicle unless activated through subscription or one-off payment (note that all stakeholder responses received on this topic stated that this was not under consideration for safety technologies). Based on these considerations and the fact that most technologies are also incentivised by Euro NCAP (Appendix A.2), the voluntary fitment rate was capped at 95%[9] in general. For three technologies the expected voluntary fitment rate was further reduced to 90%, either because they were judged to be sold more easily as a chargeable option compared to other technologies due to their directly perceivable benefit for customers and/or they are not being incentivised by Euro NCAP (ELK, RMA, TPM), or because the system would require adaptation to be deployed and maintained in GB which creates additional cost for the manufacturer (ISA).

---

[9] The strength of incentive found in this analysis was not further used due to the generally high assumed voluntary fitment rate across all technologies which was deemed to not be increased beyond 95% by Euro NCAP. Note that Euro NCAP performance requirements go beyond the regulated minimum performance however, which is why the scheme's contribution will remain relevant even after mandatory introduction.

For heavy vehicles, M2 & M3 and N2 & N3 manufacturers provided more nuanced future fitment rate estimates. The responses indicated that for some smaller manufacturers GB is the primary market and implementation of the technologies would be wholly dependent on customer specification. Other manufacturers stated that technologies would be fitted to all vehicles even in absence of legislation. A synthesis of the values provided by stakeholders was used to derive estimates, again with the assumption that voluntary fitment would in no case exceed 95% of new vehicles.

The years and voluntary technology fitment rates derived for this CBA are summarised in Table 40.

Table 40: Voluntary technology fitment rate model inputs

Vehicle category	Parameter	ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
M1	Year 1	2018	2013	n/a	2010	n/a	2014	2012	2010	2015	2008	2009	2007	n/a	2014	n/a	2000	2018	2009	n/a
M1	Year 2	2026	2024	n/a	2024	n/a	2026	2026	2024	2024	2024	2024	2024	n/a	2024	n/a	2024	2026	2024	n/a
M1	Proportion of new vehicles equipped	95%	95%	n/a	95%	n/a	95%	95%	95%	95%	90%	95%	95%	n/a	90%	n/a	95%	95%	90%	n/a
M2M3	Year 1	2023	2013	2021	2010	2009	n/a	n/a	n/a	2025	n/a	2009	n/a	n/a	2017	2021	n/a	n/a	2009	2004
M2M3	Year 2	2030	2030	2030	2030	2030	n/a	n/a	n/a	2030	n/a	2030	n/a	n/a	2030	2030	n/a	n/a	2030	2030
M2M3	Proportion of new vehicles equipped	25%	95%	75%	75%	95%	n/a	n/a	n/a	75%	n/a	95%	n/a	n/a	50%	75%	n/a	n/a	75%	75%
N1	Year 1	2018	2013	n/a	2010	n/a	2018	2018	2015	2015	2013	2009	2015	2013	2014	n/a	2009	2018	2009	2004
N1	Year 2	2026	2024	n/a	2024	n/a	2026	2026	2024	2024	2024	2024	2024	2024	2028	n/a	2024	2026	2024	2024
N1	Proportion of new vehicles equipped	95%	95%	n/a	95%	n/a	95%	95%	95%	95%	90%	95%	95%	95%	90%	n/a	95%	95%	90%	90%
N2N3	Year 1	2023	2013	2021	2010	2016	n/a	n/a	n/a	2025	n/a	2009	n/a	n/a	2021	2021	n/a	n/a	2009	2004
N2N3	Year 2	2030	2030	2030	2030	2030	n/a	n/a	n/a	2030	n/a	2030	n/a	n/a	2030	2030	n/a	n/a	2030	2030
N2N3	Proportion of new vehicles equipped	25%	95%	75%	75%	75%	n/a	n/a	n/a	75%	n/a	95%	n/a	n/a	50%	75%	n/a	n/a	75%	75%

C.4 Vehicle fleet data

C.4.1 About vehicle fleet data

Vehicle fleet inputs were provided by DfT based on the DfT's National Transport Model (NTM) and Road Carbon and Fuel Fleet (RoCaFF) model for 2020 up to 2050. Two inputs were required in terms of the vehicle fleet:

1. The number of licensed vehicles projected for each year
2. The number of new vehicles projected to enter the fleet each year

The data were broken down by vehicle type, year, fuel type and road type.

The NTM uses various assumptions and parameters about how transport may change over the period (Department for Transport, 2022). Year-on-year data were provided for three scenarios: Core, vehicle-led decarbonisation and mode-balanced decarbonisation:

- The **Core Scenario** is based on the latest government projections of the main drivers of road traffic demand, for example population, GDP, employment, households, fuel prices and fuel efficiency. The core also includes 'firm and funded' government policy, for example, where ambitions are supported by published plans or funded policies. Relationships between the key drivers of demand and road traffic are broadly assumed to continue in line with historical trends and evidence, for example, how drivers respond to changes in fuel costs or how changes in GDP influence peoples travel choices.
- The **Vehicle-led Decarbonisation Scenario** and **Mode-balanced Decarbonisation Scenario** both assume a high and fast uptake of eVs and ZEVs, in line with stated ambitions to end the sale of diesel and petrol cars, vans, HGVs and buses/coaches by 2030. In both scenarios, vehicle fleet electrification approaches 99% by 2050.
    - In the **Vehicle-led Decarbonisation Scenario**, no other adjustments are made compared to the Core Scenario. The current cost regime for EVs is maintained. Making the use of cars cheaper over time, as the fleet electrifies, leads to higher car use, more congestion and reductions in the use of other modes including public transport.
    - The **Mode-balanced Decarbonisation Scenario** represents a world where the assumed increase in eVs does not result in a decline in public transport use. This was modelled simply by equalising the perceived costs of eVs with those of petrol and diesel. This removes the cost advantage of eVs and creates a slight cost disadvantage compared to current conditions making the usage of public transport, walking and cycling more attractive.

C.4.2 Number of vehicles in fleet

The two figures below show examples of the change in projected fleet numbers:

Figure 15 shows the projected slight increase in the number of cars each year meaning that the total number of cars increase from 33 million in 2019 to an estimated 36 million by 2030.

Figure 16 shows the trend for bus/coaches between 2019 and 2030. In each of these years there is a small net decrease in the number of vehicles each year and hence the dropouts each year is greater than the number of new vehicles.

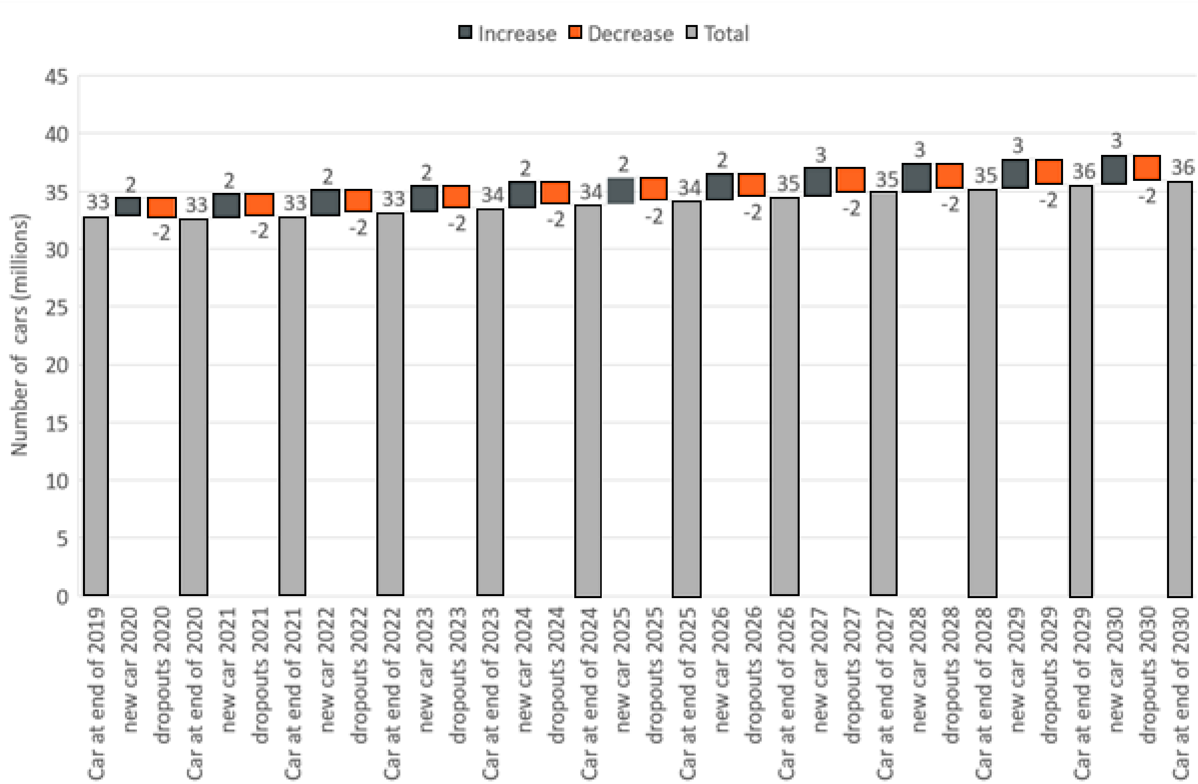


Figure 15: Example of changes to car fleet 2019 to 2030

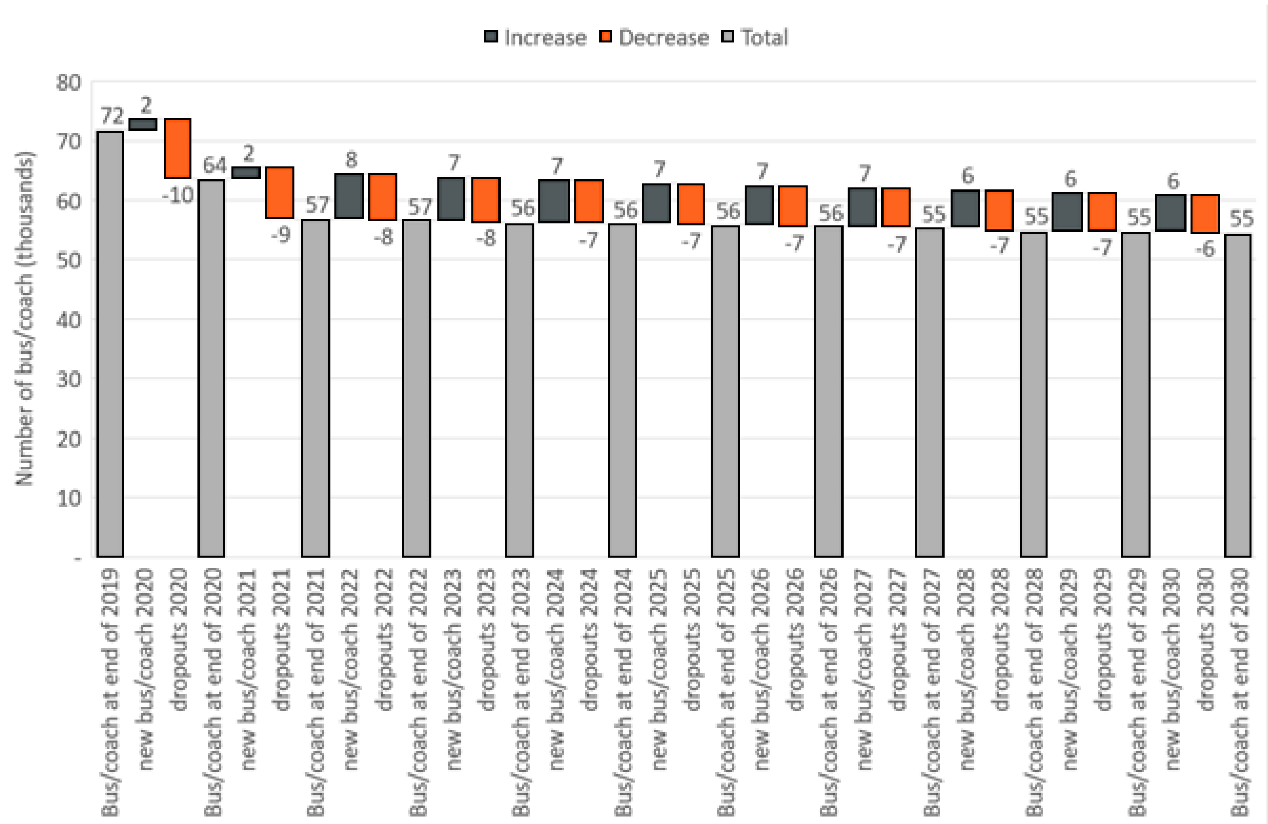


Figure 16: Example of changes to bus/coach fleet 2019 to 2030

The number of vehicles projected in the future was the same for the core, vehicle-led and mode-balanced decarbonisation. Table 41 shows the number of vehicles in the fleet in 2010 and the projection in 2050 for each of the four vehicle categories.

Table 41: Number of vehicles in 2010 and projected in 2050 by vehicle type

Vehicle category	2010	2050	2050 % increase from 2010
Car (M1)	29,287,260	43,728,268	49%
Bus and Coach (M3)	77,000	49,948	–35%
Van (N1)	3,399,097	6,367,422	87%
HGV (N2N3)	494,807	534,898	8%
Total	**33,258,164**	**50,680,536**	**52%**

This shows a projected increase of 52% overall by 2050. The largest increase is projected for vans (87%); this increase means that they increase from 10% of the fleet in 2010 to 13% in 2050. HGVs have a much smaller projected increase (8%), and the number of buses and coaches is predicted to decrease by 35%. Note that NTM and RoCaFF include minibuses (vehicles with 8 to 16 passenger seats) in the group 'van' (see Section 3.3 for information how this was addressed for the CBA).

The difference between the scenarios is in the different powertrains as shown below. The core scenario is expected to have large increases in Battery Electric Vehicles (BEV) and Plug-in Hybrid Electric Vehicles (PHEV) and a reduction of Internal Combustion Engine (ICE) vehicles, whereas in the decarbonisation scenarios the majority of the 2050 fleet is expected to be BEV.

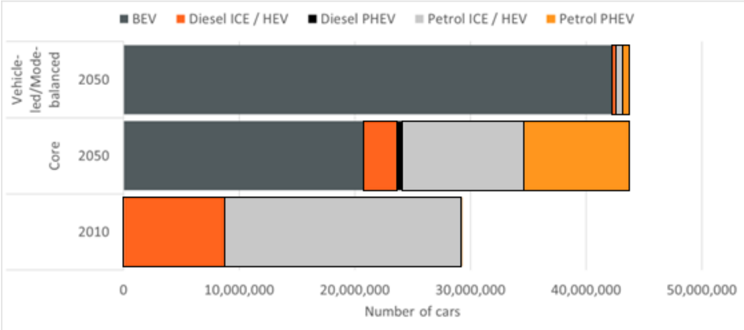


Figure 17: Number of cars in 2010 and projected in 2050 by powertrain (core scenario)

C.4.3 New vehicles in fleet

The number of new vehicles in the fleet was the same for the core and decarbonisation scenarios; as with the total fleet, the difference between the scenarios is in the powertrain type, as shown in Figure 18. This shows that, as with the total fleet, the number of new vehicles is increasingly made up of BEV and new ICE vehicles are eliminated.

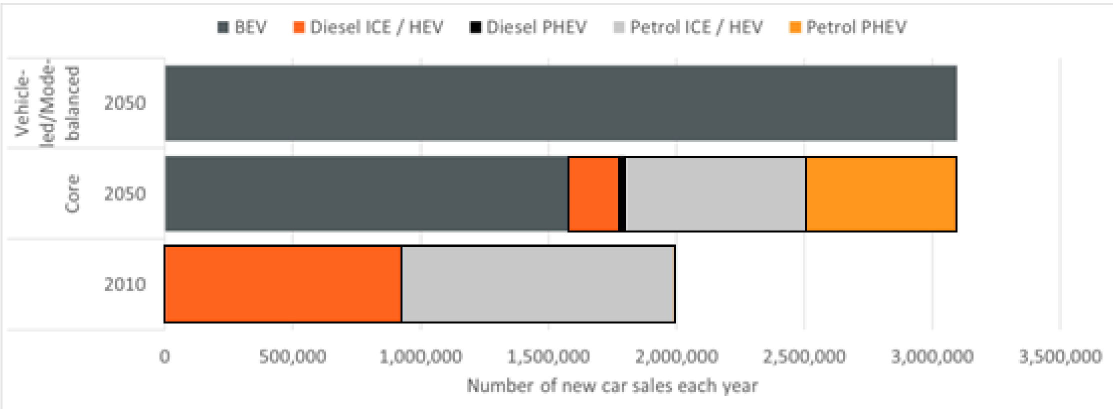


Figure 18: Number of new car sales in 2010 and projected in 2050 by powertrain (core scenario)

C.5 Casualty and collision data

The casualty and collision data used for this study were taken from the STATS19 database of reported injury collisions. This database holds detailed records of collisions and casualties, collected by the police for Great Britain since 1979. It is the single most useful source of data on road collisions and casualties in Great Britain, providing detailed information on collisions, vehicles, and casualties. The database holds statistics on collisions in which at least one person was injured on the highway and involving at least one vehicle, including pedal cycles and ridden horses.

The severity of each casualty was, until 2015 for all forces and for about half of forces since 2015, determined by the police as killed, seriously injured and slightly injured. Killed refers to those who sustained injuries that resulted in death less than 30 days after the collision. The distinction between slight and severe injuries is made by assessing the extent of injury sustained. This does not involve critical medical examinations; however, whether the casualty required medical treatment or not may influence the severity recorded.

About half of police forces in Great Britain have started using Injury Based Reporting Systems (IBRS) when recording collision data since 2015. With this system, the police officer records the injuries sustained by the casualty and the severity level is automatically assigned using those injury details. This results in a more accurate casualty severity level; however, the use of IBRS led to an increase seriously injured numbers because more casualties were being classed as seriously injured than under the previous system. Therefore, DfT published a set of adjustment factors each year which enable seriously injured and slightly injured casualty numbers from 2005 onwards to be calculated as though they had been recorded using an IBRS (the number of fatalities is not affected by the reporting system change). The adjustment factors for all years from 2005 onwards are updated each year when the latest year of STATS19 data is released to account for changes that occur when more data is added to the statistical model.

In this study the adjusted severity casualty figures were used.

Casualty and collision data were used in three ways as part of the model:

1. To calculate the casualty baseline. That is, the number of people estimated to be killed or injured in a given period or scenario (Appendix C.5.1).
2. To calculate target populations. That is, the number or percentage of casualties that may be affected by a technology (Appendix C.5.2).
3. Collision constants to provide the average number of collisions for a given number of casualties (Appendix C.5.3).

C.5.1 Casualty baselines

C.5.1.1 Data to create casualty baselines

There are several factors that influence the number and severity of road deaths and injuries. The largest influence is the amount of traffic on the network. Other influences include the road infrastructure, environmental factors, vehicle safety features and road user behaviours. Usually, a combination of these factors contributes to the occurrence and severity of a given crash. This makes it almost impossible to clearly correlate a crash to a particular cause/factor. Given this complexity, it is difficult to segregate the factors that influence crashes into the safe system approach.

Therefore in this study just two types of data were used to create the baselines, described below:

1. Casualty data from STATS19
2. Traffic data (actuals plus projections)

Casualty data

The casualty data from STATS19 used covers the period from 2005 to 2021 (Figure 19 shows the trends relative to the 2005 to 2009 average). For this analysis, separate trends were generated for each of the three severity classifications, using the CRASH[10] adjusted figures for the seriously injured and slightly injured.

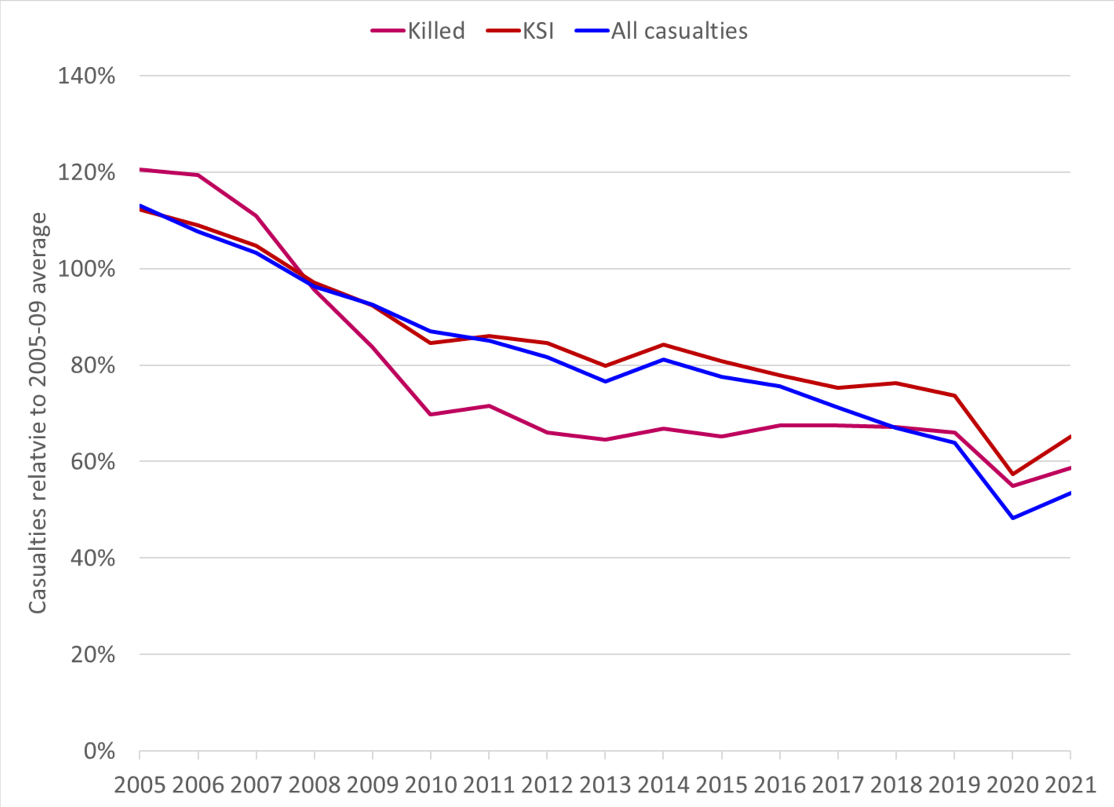


Figure 19: Number of casualties by severity relative to 2005-09 average (2005-2021)

All three casualty severities generally show a reducing trend; this is due to a large number of factors including road engineering improvements and changes to driver behaviours.

[10] DfT provide an adjustment factor for each casualty to account for differences in how severity is reported https://www.gov.uk/government/publications/guide-to-severity-adjustments-for-reported-road-casualty-statistics/guide-to-severity-adjustments-for-reported-road-casualties-great-britain

Traffic data

The largest effect on casualty numbers is the amount of traffic travelling on the road network. Traffic data from the DfT was used to analyse the casualty and collision rates. The observed data (Department for Transport, 2023) covers the period from 2005 to 2021.

The projected traffic data, extending from 2021 to 2040, was provided by the DfT. This is similar to the published projections, which cover England and Wales only (Department for Transport, 2022) but covers all of GB.

The projections cover the same scenarios as the vehicle fleet, and three scenarios were selected for analysis in this project (see Appendix C.4.1).

In all scenarios, an increase in road traffic has been projected. Figure 20 shows the trends in the observed traffic levels and the three projections used.

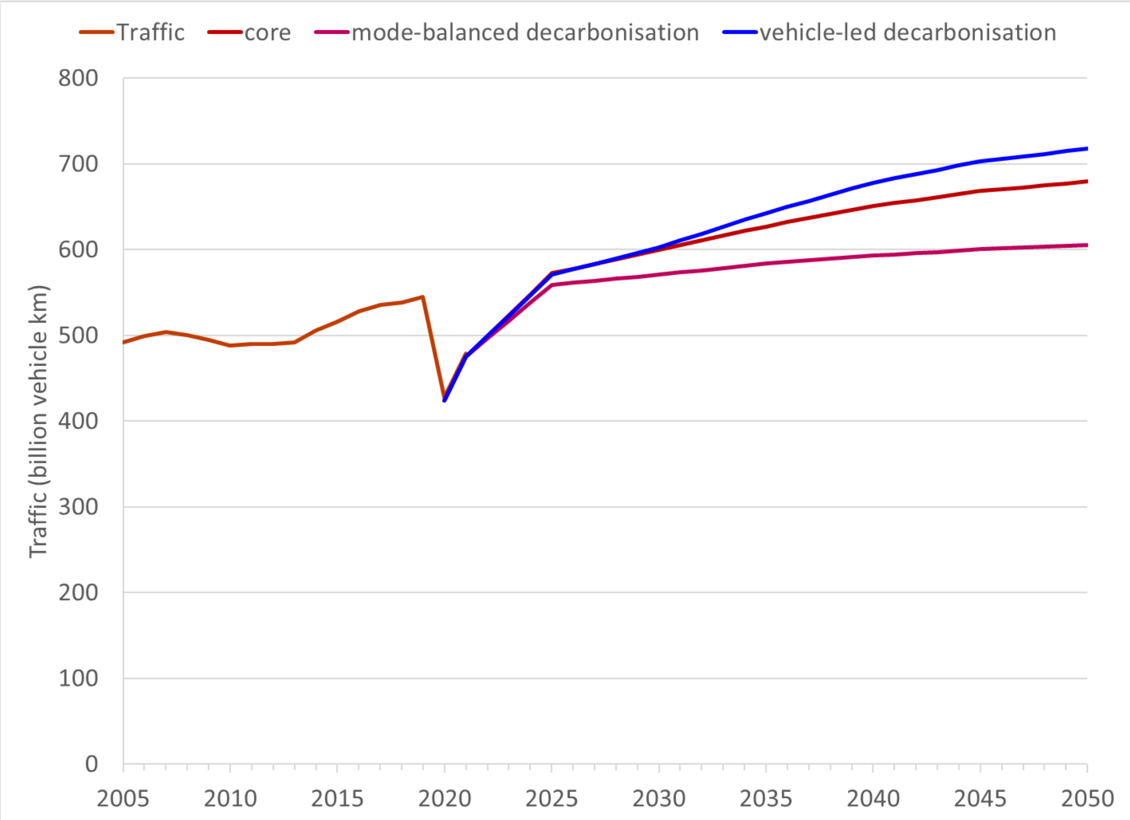


Figure 20: Observed traffic data (2005–2021) and projections (2021–2050)

C.5.1.2 Method for casualty baselines

The trend observed in collisions or casualties has been explored in several studies ((Broughton, Forecasting road accident casualties in Great Britain, 1991), (Broughton, Updated post-2010 casualty forecasts. PPR552, 2011), (Elvik & Høye, The potential for reducing the number of killed or seriously injured road users in Norway in the period 2018-2010, 2020) (Elvik & Hoye, Do we know why the number of traffic fatalities is declining? If not, can we find out?, 2022) (Sexton & Johnson, 2009)) for the purposes of both understanding historic trends, projecting them into the future and assessing the benefits of potential future measures to improve safety. Whilst the overall trends can be simply modelled mathematically, understanding the reasons for the trend is more complex. The level of traffic has the greatest effect on the number of casualties or collision on the network (Elvik & Vaa, The Handbook of Road Safety Measures, 2004). There are also changes in road engineering, vehicle safety and road user behaviour that contribute to these trends.

In this study, two approaches were used to project future casualties (described in detail in the following sections):

- the use of collision reduction factors (called 'beta factors') used as part of the DfT's TAG (Department for Transport, 2023)
- using updated collision rate data to create updated beta factors

Two other approaches were considered but not used:

- the log-linear approach with secondary safety adjustment; this was used previously by TRL in similar projects; however, this was not used in this project because the trend is highly dependent on where the start point is, there is no knowledge of the cause of the trend and it is partly covered by the updated TAG method, which appeared a better fit.
- A third method (Elvik & Høye, The potential for reducing the number of killed or seriously injured road users in Norway in the period 2018-2010, 2020) was not possible as this relied on previous work that was from Norway and there was no equivalent study for GB.

TAG data book method

The TAG data book method was used to compute the number of casualties. For the projections in this method, beta values from the DfT's Transport Analysis Guidance (TAG) book (Department for Transport, 2023) were used. The TAG book serves as a reliable resource for transportation modelling and analysis. The beta values indicate how collision rates are likely to alter over time. The beta values were classified to reflect the differences in collision rates along the various road types. The beta values were calculated based on the historic trend, assuming a constant percentage reduction in the collision rate annually. This trend therefore includes all elements that have contributed to the trend, although the contribution of each is not known.

The steps used in this method are as follows:

1. The number of collisions was extracted from STATS19 by road type. This was categorized into motorways, minor roads and major roads.
2. Traffic data from DfT (DfT, 2023) was used to calculate collision rates from 2005 to 2021.
3. Beta factors from the TAG data book were grouped into categories to match up with the data on collision rates. The TAG beta factors used are shown below.

Table 42: TAG beta factors used

Period	Motorways	Major road – rural	Major road – urban	Minor road – rural	Minor road – urban
2004–2019	0.956	0.953	0.959	0.933	0.951
2020–2029	0.978	0.976	0.980	0.967	0.976
2030–2039	0.989	0.988	0.990	0.983	0.988
2040+	1	1	1	1	1

For example, the beta factor for motorways for 2004-2019 is 0.956 i.e. the collision rate reduces by 4.4% per year. Between 2020 and 2029 the collision rate reduction slows to a 2.2% reduction per year, then to 1.1% between 2030-2039 and assumed to remain constant from 2040 onwards.

4. The average beta factor for each road type was then used to project collision rates (number of collisions per billion vehicle miles) from 2022 to 2040 as shown below

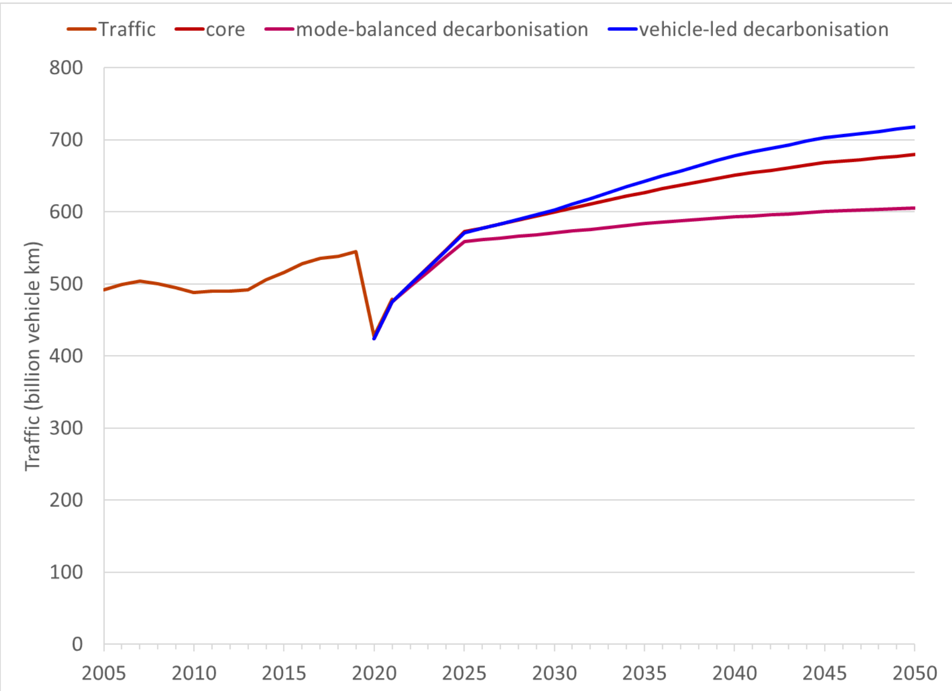


Figure 21: Motorway collision rate (collisions per billion vehicle miles) 2005-2021 and projection using beta factors

5. Using DfT's traffic projections scenarios the number of collisions were then forecasted.
6. Initially, to estimate actual casualties from the collisions, casualties per collision figures from the TAG book were used but outcomes were inconsistent. This was because the average number of casualties per collision in TAG was very different to

that observed from STATS19, as shown in Table 43. Therefore, STATS19 data was used to provide the average number of casualties per collision, and this was applied which gave a better outcome.

Table 43: Casualties per collision by severity and road type from TAG and STATS19

Road type	Method	Killed per collision	Seriously injured per collision	Slight casualties per collision	Total casualties per collision
Motorway	**TAG**	0.016	0.099	1.484	1.600
	STATS19	0.030	0.230	1.304	1.565
A urban	**TAG**	0.008	0.113	1.225	1.347
	STATS19	0.009	0.209	1.002	1.221
A rural	**TAG**	0.026	0.165	1.299	1.490
	STATS19	0.037	0.334	1.063	1.434
Minor urban	**TAG**	0.006	0.130	1.143	1.279
	STATS19	0.007	0.230	0.950	1.187
Minor rural	**TAG**	0.023	0.199	1.194	1.415
	STATS19	0.024	0.348	0.968	1.339

7. The number of casualties for each severity and each scenario was calculated, an example is shown in Table 44.

Table 44: TAG method – 2040 projections – all roads

Road type	Traffic scenario	Killed	Serious	Slight
All roads	**Core**	1,433	23,574	92,569
All roads	**Mode-balanced decarbonization**	1,203	21,140	83,919
All roads	**Vehicle led decarbonization**	1,509	25,090	98,673

Combined approach (new beta)

The second approach was similar to the first but used STATS19 data to calculate new beta values based on data from 2005 to 2021, because the beta values in TAG are based on STATS19 data up to 2010. This gives a lower estimate of casualties and was used with the lower traffic projection (mode-balanced decarbonisation) to give an overall low casualty estimate.

The beta factors in TAG were developed by analysis of historic collision rates on different road types, using a log-linear approach applied to casualty rates (i.e. assuming that the collision rate falls by the same percentage each year). This has historically been a well-fitting trend.

Therefore, in this approach, the log-linear trend of the collision rates was computed for motorways and A-roads. This gave a 'new beta' value that was applied to the 2021 collision rates. As in the TAG method, this new beta was assumed to apply for ten years, before halving, then quarter, and then assumed to be constant.

The collision rates were multiplied by the traffic scenarios and converted to casualties using the STATS19 data.

Table 45 shows an example of the output for 2040.

Table 45: New beta approach – 2040 projections – all roads

Road type	Traffic scenario	Killed	Serious	Slight
All roads	**Mode-balanced decarbonisation**	902	16,907	68,037

C.5.1.3 Resulting casualty baseline

Discussions with DfT were held and it was agreed to calculate three baselines (to allow sensitivity analysis, see Section 3.5):

1. TAG approach for core scenario (this will represent the 'medium' casualty baseline)
2. TAG approach for vehicle-led decarbonisation scenario ('high' casualty baseline)
3. New beta approach for mode-balanced decarbonisation ('low' casualty baseline)

The second baseline gives the highest number of casualties projected; this is a pessimistic future view of the number of casualties, but because the cost-benefit analysis is based on percentage reductions in casualties from the baseline, the number of casualties prevented in this scenario is greater.

Similarly, the third baseline represents an optimistic scenario of the future casualty trend and therefore the number of casualties that could be prevented by the new technologies is lower.

Table 46 summarises the number of casualties projected for the year 2040 for each of the three baselines.

Table 46: Baseline scenario methods, traffic scenarios and casualty numbers projected for year 2040 and change relative to year 2021

Baseline scenario	Method	Traffic scenario		Killed	Serious	Slight
2021 actual value				1,558	25,892	100,759
High	**TAG**	**Vehicle-led decarb.**	**Year 2040 projection**	1,509	25,090	98,673
			Change from 2021	−3.1%	−3.1%	−2.1%
Medium	**TAG**	**Core**	**Year 2040 projection**	1,433	23,574	92,569
			Change from 2021	−8.0%	−9.0%	−8.1%
Low	**New beta**	**Mode-balanced decarb.**	**Year 2040 projection**	902	16,907	68,037
			Change from 2021	−42.1%	−34.7%	−32.5%

Figure 22, Figure 23 and Figure 24 show the observed numbers of casualties from 2005 to 2021 and the projected high, medium and low baselines for killed, seriously and slightly injured casualties respectively.

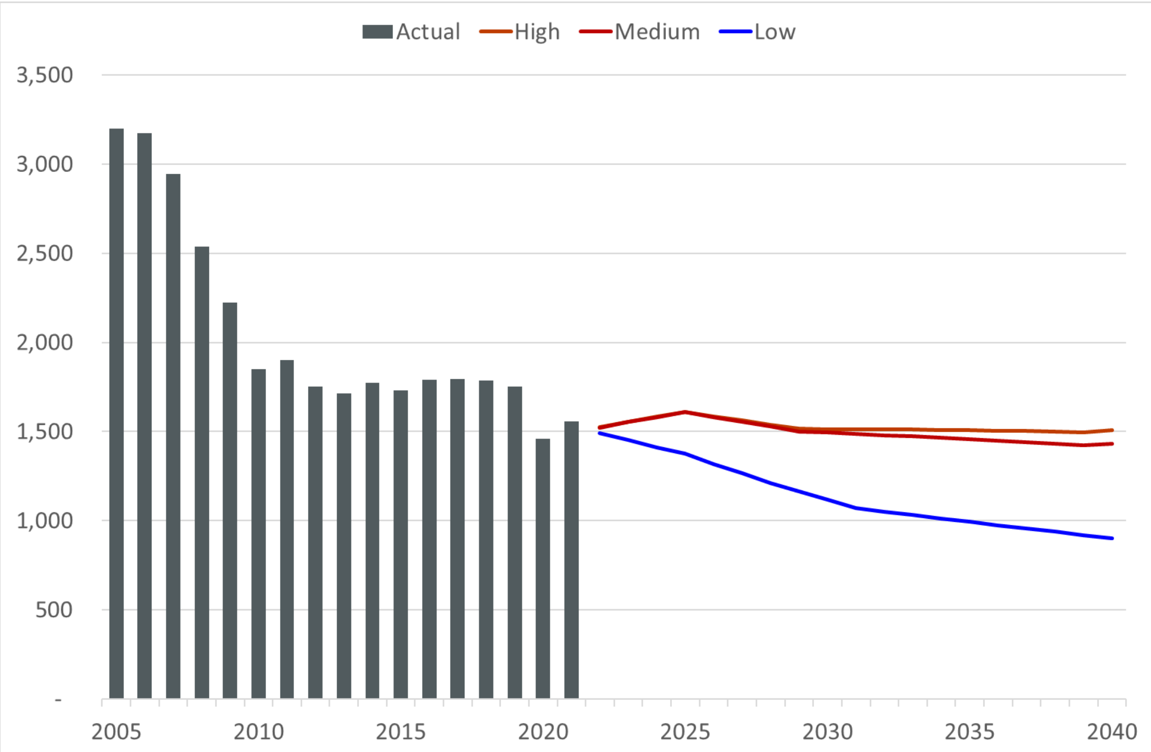


Figure 22: Casualty baselines – Killed

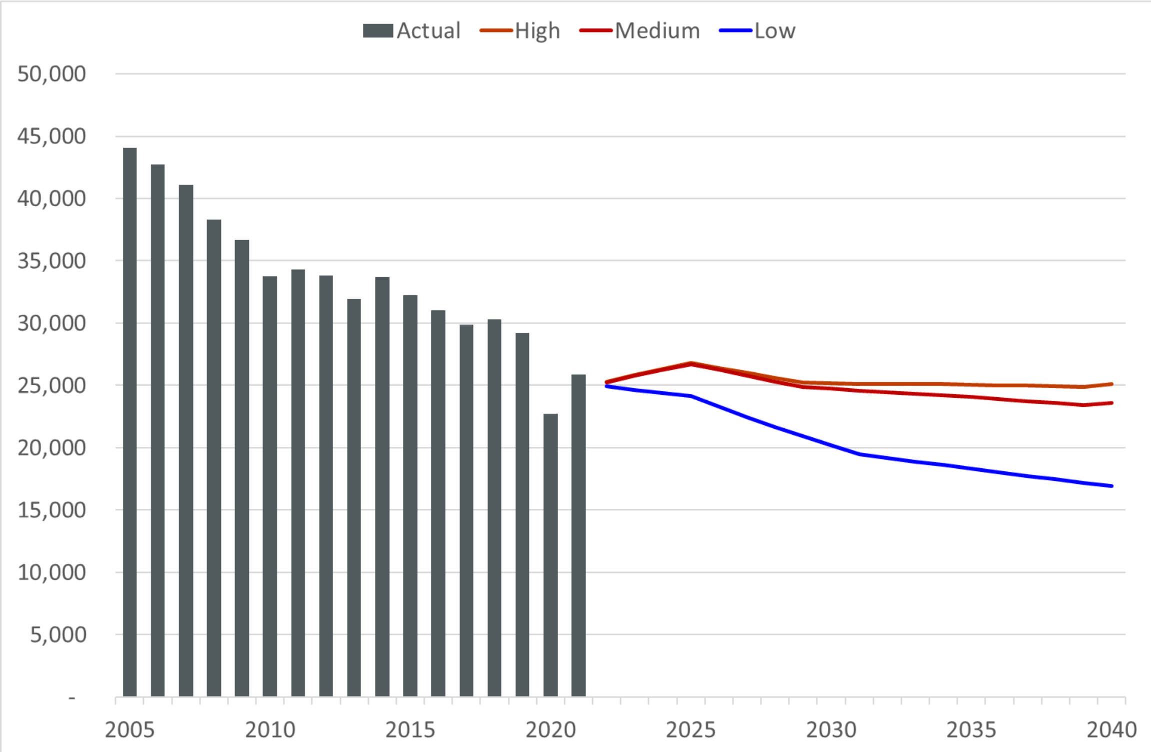


Figure 23: Casualty baselines – Seriously injured

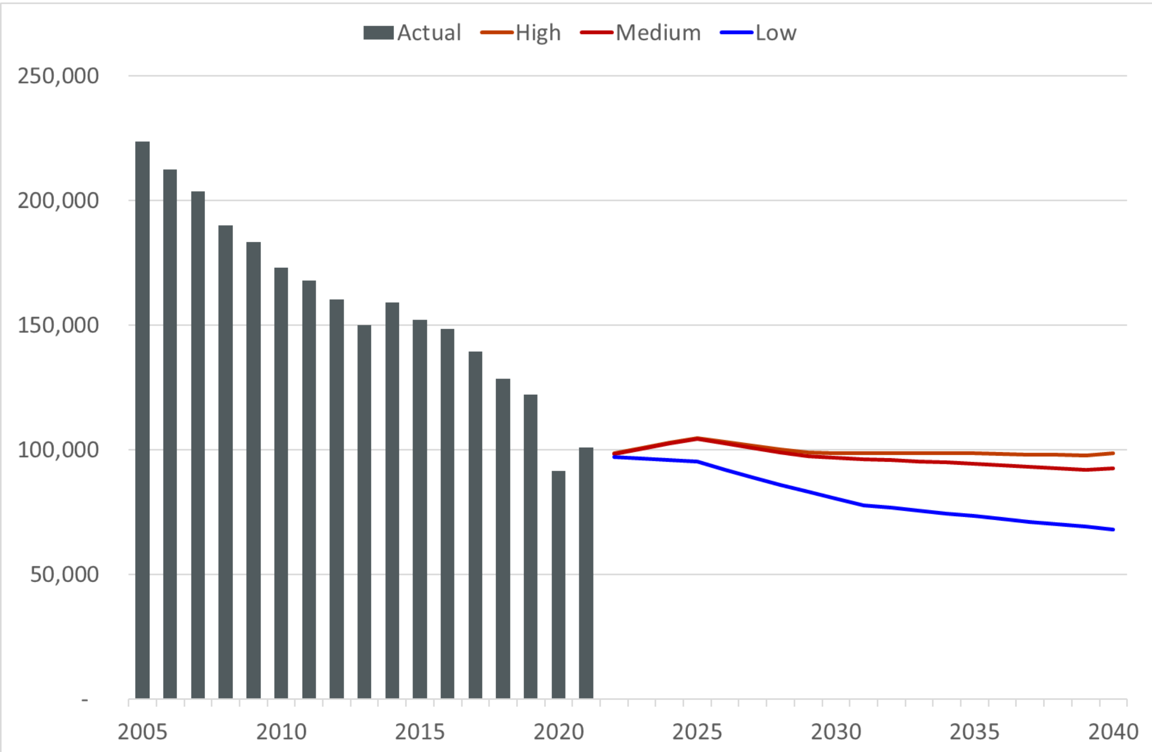


Figure 24: Casualty baselines – Slightly injured

Adjustment for under-reporting of road casualties

Comparison between death statistics and fatalities in STATS19 shows that few road casualties are not reported by the police. However, there is evidence that a considerable proportion of non-fatal casualties are not reported to the police and hence do not appear in STATS19 data (DfT, 2021).

Since 2007, the National Travel Survey (NTS) has asked respondents in England whether they have been involved in road collisions on public roads in GB, the type of collision and whether the police attended or whether they reported the collision later. These data, therefore, can be compared with STATS19 to estimate the total number of collisions or casualties. Table 47 shows the estimated number of casualties recorded in STATS19 and estimated from NTS (DfT, n.d.). The ratio of these shown in the final column can be used as a correction factor for under-reporting.

Table 47: Comparison of casualty numbers from NTS and STATS19

Casualty age grouping	Breakdown type	Sum of NTS central estimate (thousands)	Sum of STATS19 injured casualties (thousands)	NTS/STATS19
Adults	**All road casualties**	1,320	422	3.13
	Car occupants	910	253	3.60
	Motorcyclists	80	50	1.60
	Others	50	27	1.85
	Pedal cyclists	210	46	4.57
	Pedestrians	90	46	1.96
Children	**All road casualties**	110	42	2.62
All ages	**All road casualties**	1,430	473	3.02
	Seriously injured	260	88	2.95
	Slightly injured	1,170	385	3.04

Although there are differences in the levels of under-reporting for each road user type and age group, in this study it was decided to use the ‘all ages’ ratios for seriously injured (2.95) and slightly injured (3.04), that is, that the actual number of serious and slight casualties is approximately three time that recorded in STATS19. No more detail is known on the collisions that go unreported, but it could be assumed that their injury outcomes are likely to be at the lower end of each severity spectrum, which should be noted as a limitation of this approach. No factoring was applied for killed. These factors were applied to the casualty baseline figures calculated above.

Figure 26 and Figure 26 show the actual number of casualties, the baselines based on these and the factored baselines to account for under-reporting of serious and slight casualties.

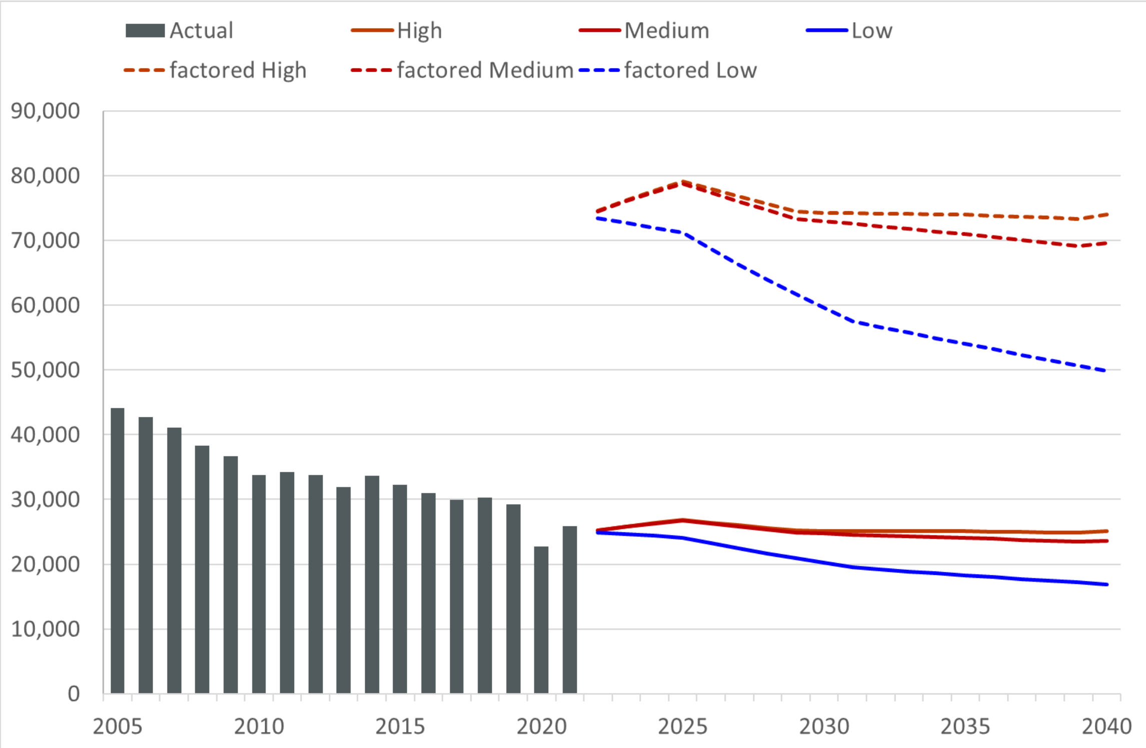


Figure 25: Casualty baselines factored for under-reporting – Seriously injured

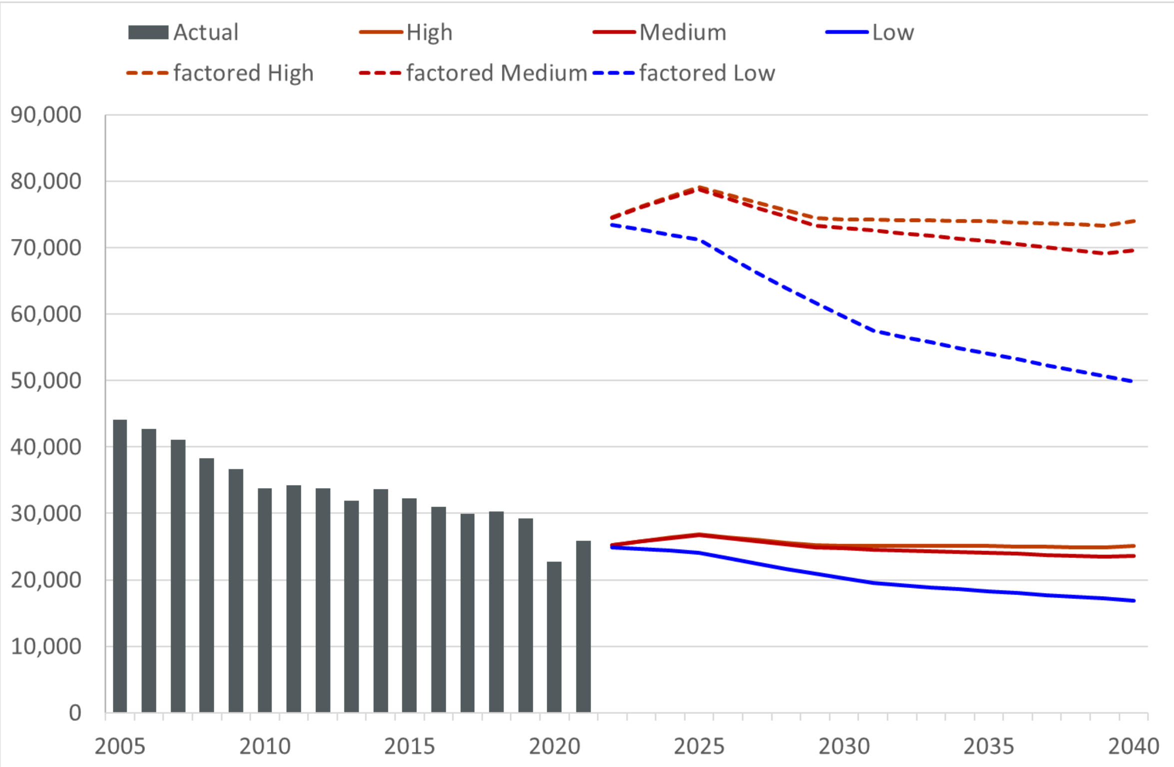


Figure 26: Casualty baselines factored for under-reporting – Slightly injured

Baselines for VRUs and vehicle occupants

Baselines were also produced for VRUs and vehicle occupants so that the casualty savings could be disaggregated into these groups, but this split was ultimately not reported because it did not impact on the economic indicators reported. Because the number of casualties in these groups is smaller (especially for killed) this can lead to a less stable trend. Therefore, the baselines for each severity were split into a VRU (pedestrian, pedal cyclist, motorcyclist, horse rider, mobility scooter) and vehicle occupant (all other users) baseline based on STATS19 data for the five-year period (2016 to 2019, 2021). Table 48 shows the percentage of each casualty severity that were VRUs and vehicle occupants.

Table 48: Proportions of casualties that are VRUs and vehicle occupants by severity and year (average 2016 to 2019, 2021)

Severity	Vehicle occupants	VRUs
Killed	48.8%	51.2%
Serious	42.5%	57.5%
Slight	69.3%	30.7%

Baselines for casualties in collisions involving vehicle types

Baselines were also created for each severity for the following groups of casualties so that the results could be split into these groups, if required:

- Casualties in collisions involving an M1 vehicle
- Casualties in collisions involving an N1 vehicle
- Casualties in collisions involving an M3 vehicle
- Casualties in collisions involving an N2 or N3 vehicle

Because a collision can involve more than one vehicle, there is an overlap between these subsets and therefore these subsets should not be summed (as this will double count collisions – e.g. casualties in collisions involving both an M1 and N1 vehicle).

The percentage of casualties in each group was calculated based on STATS19 data for the five-year period (2016-19, 2021) and shown below.

Table 49: Proportion of total casualties that were in each type of collision (average of years 2016–2019 and 2021) used for future years' baselines

Vehicle type	Casualty type	Killed	Serious	Slight
M1	All	77.9%	82.4%	90.8%
M1	VRU	32.8%	42.4%	24.1%
M1	Vehicle occupants	45.1%	40.0%	66.7%
N1	All	11.4%	9.5%	10.9%
N1	VRU	5.0%	4.5%	2.3%
N1	Vehicle occupants	6.4%	5.0%	8.6%
M2M3	All	3.1%	2.9%	3.8%
M2M3	VRU	1.9%	1.3%	0.7%
M2M3	Vehicle occupants	1.2%	1.6%	3.1%
N2N3	All	14.8%	3.9%	3.9%
N2N3	VRU	6.2%	1.1%	0.4%
N2N3	Vehicle occupants	8.5%	2.8%	3.5%

C.5.2 Casualty target populations

STATS19 data was used to extract target populations for the previous five years (2016 to 2019, 2021). 2020 was excluded as the casualty patterns were different due to the COVID-19 pandemic.

C.5.2.1 STATS19 definitions of target populations

Target populations were defined to match with target population descriptions used in the studies from which technology effectiveness factors were extracted (see Appendix C.6.1). In some cases, the actual number of collisions and casualties that are likely to be affected by the measure might be smaller, but it is important that they match with the effectiveness estimate populations. For two technologies, EDR and ISA, the target population was defined as 'all casualties in collisions involving the vehicle of interest' because the underlying effectiveness studies also reported their results in relation to all road casualties.

Each casualty was labelled as to what target populations it belongs to. This meant that there is certainty in the overlaps between the combinations of measures. The number of VRU and vehicle occupant casualties in each combination of target population was calculated.

Some of the queries used to identify the target populations were complex. These were independently reviewed to ensure that these were as accurate as possible. Table 50 shows the definitions of the target populations for each technology; Table 51 shows the number of casualties by severity.

Note that for most of the technologies the table shows the target population as 'all casualties' in the affected collisions. In some collisions there may be a vehicle of interest in each category; the casualties in this collision will therefore be counted in both target populations and therefore it is not correct to add up the casualty numbers for each technology.

Table 50: STATS19 definition of target population per technology

Technology	Target population definition	Notes
ADW	All casualties in collisions attended by the police with vehicle of interest having contributory factors CF508 (driver using mobile phone) CF509 (distraction in vehicle), or CF510 (distraction outside vehicle),	CF508 includes hands-held and hands-free phones which might not be detectable by ADW
AIF	All casualties in collisions attended by police with vehicle of interest having contributory factor CF501 (impaired by alcohol)	CF501: Driver/rider was affected by alcohol and behaved in a way which caused, or contributed to, the collision – whether or not they were above the legal limit.
BSI	Cyclist casualties in vehicle to cycle two-vehicle non pedestrian collisions with vehicle of interest with 1st point of impact = nearside	
DAW	All casualties in collisions attended by police with vehicle of interest having contributory factor CF503 (fatigue)	
DIV	(a) Pedestrian casualties in single vehicle + pedestrian. First point of impact for veh = front or side (b) Cyclist casualties in 2 vehicle collision with ped cycle + vehicle type. First point of impact for vehicle = front or side	
EBC	Cyclist casualties, number of vehicles = 2 (1 Vehicle, 1 Cycle) AND no pedestrians	
EBP	Pedestrian casualties only. Collisions involving pedestrian and one vehicle. Vehicle manoeuvre NOT reversing.	
EBV	Two-vehicle (non-pedestrian) collisions. Involving vehicle category vehicle (e.g. M1) first point of impact = front and other vehicle NOT ped cycle, motorcycle, horse, mobility scooter	
EDR	All casualties in collisions with vehicle of interest	

Technology	Target population definition	Notes
ELK	All casualties in collisions with speed limits of >= 40mph without ice/snow road surface condition in: (a) single vehicle collisions (b) head on collisions (i.e. 2 vehicles in collision were travelling in approximate opposite directions and had first point of impact front and front)	Note: some collisions on multi-lane roads may not end up as head-on collisions
ESS	All casualties in 2 vehicle non pedestrian collisions attended by police with speed limit >30mph where Vehicle of interest had 1st point of impact = rear AND other vehicle (excluding PTWs and cycles) has 1st point of impact front AND Vehicle of interest had CF408 (sudden braking)	In theory the sudden breaking factor should be assigned to the front vehicle but in practice it may be sometimes incorrectly assigned to the rear vehicle. Therefore, this target population includes those with either vehicle in the collision with sudden braking factor.
FFI	Front row occupants of vehicle of interest in collisions where 1st point of impact = front.	Assume that N1 occupants are all front row. For M1 use drivers + 'car passenger' = front seat passenger
FOI	All occupants of vehicle of interest in collisions where 1st point of impact = front	
ISA	All casualties in collisions with vehicle of interest	
MOI	(1) Pedestrians in single vehicle collisions where vehicle first point of impact = front (2) cyclists in 2 vehicle (non-pedestrian) collisions and 1st point of impact = front	
PSI	All casualties in front seats (assume N1 occupants are in front seats) in single vehicle type (non-pedestrian) collisions with 1st point of impact = offside (3) or nearside (4) which hit off carriageway object road sign (01), lamp post (02), telegraph pole (03), tree (04)	Excludes multi-vehicle collisions as STATS19 does not give what was impacted first
PWI	(a) Pedestrian casualties in single vehicle + pedestrian. First point of impact for vehicle = front (b) Cyclist casualties in two-vehicle collisions involving bicycle + vehicle type. First point of impact for vehicle = front	
RMA	Collisions where vehicle of interest had vehicle manoeuvre = reversing	
TPM	All casualties in collisions attended by police with vehicle type having contributory factor CF201 (tyres illegal, defective or under-inflated)	Note that TPM monitors tyre pressure and does not monitor illegal or defective tyres

Table 51: STATS19 total number of casualties in target populations based on above definitions by severity (years 2016 to 2019 and 2021, not accounting for under-reporting or misclassifications); note: target populations overlap, i.e. individual casualties appear in more than one population

Technology	Vehicle category	Killed	Serious Adj	Slight Adj
ADW	M1	388	4,292	21,497
	M2M3	2	65	447
	N1	54	408	1,946
	N2N3	72	196	779
AIF	M1	550	6,575	20,296
	M2M3	0	4	17
	N1	37	412	1,124
	N2N3	12	36	80
BSI	M2M3	3	96	300
	N2N3	32	147	254
DAW	M1	204	2,145	7,309
	M2M3	0	17	94
	N1	41	210	639
	N2N3	20	100	237
DIV	M2M3	119	1318	2,863
	N2N3	290	720	1,094
EBC	M1	230	15,949	52,131
	N1	37	1,566	4,505
EBP	M1	1,207	21,770	50,663
	N1	128	1,689	3,678
EBV	M1	1,515	26,431	220,170
	N1	222	2,586	19,104
EDR	M1	6,765	120,599	580,342
	M2M3	269	4,227	24,380
	N1	957	13,331	66,115
	N2N3	1,245	5,530	23,397
ELK	M1	2,191	18,187	46,742
	N1	218	1,445	3,246
ESS	M1	4	294	4,732
	M2M3	0	0	41
	N1	0	23	287

Technology	Vehicle category	Killed	Serious Adj	Slight Adj
	N2N3	3	26	121
FFI	M1	2,223	32,600	161,895
	N1	162	1,874	8,285
FOI	NI	162	1,874	8,285
ISA	M1	6,765	120,599	580,342
	M2M3	269	4,227	24,380
	N1	957	13,331	66,115
	N2N3	1,245	5,530	23,397
MOI	M2M3	90	761	1,446
	N2N3	195	319	417
PSI	M1	174	937	2,026
	N1	6	21	60
PWI	M1	1,206	21,878	56,352
	N1	120	1,553	3,308
RMA	M1	81	2,215	11,665
	M2M3	0	15	80
	N1	20	401	1,969
	N2N3	19	82	391
TPM	M2M3	0	0	2
	N1	1	46	134
	N2N3	3	19	43

Overall there were 794,341 casualties recorded in STATS19 in the 5-year study period (Table 52). Approximately 5% of these casualties were not in any of the target population. These were mainly motorcyclists.

Table 52: Total casualties in STATS19 (2016 to 2019, 2021) by road user type (not accounting for under-reporting or misclassifications)

Casualty type	Severity	All casualties	Casualties not in any target population	% of casualties not in any target population
Vehicle occupant	Killed	4,238	54	1.3%
	Serious	62,157	505	0.8%
	Slight	444,372	1,038	0.2%
VRU	Killed	4,441	707	15.9%
	Serious	84,187	13,565	16.1%
	Slight	194,946	21,822	11.2%
All casualties	Killed	8,679	761	8.8%
	Serious	146,344	14,070	9.6%
	Slight	639,318	22,860	3.6%

C.5.2.2 Casualty correction factors

There were three types of factoring based on the STATS19 data. These are due to misclassified data within STATS19 such that the target populations calculated may under-represent the actual number of casualties in each. Note that these factors do not account for any under-reporting in STATS19.

- Goods vehicles with unknown weights
- Collisions which were not attended by the police or did not have any contributory factors recorded
- Any other technologies, vehicle types or severities where there was evidence for mis-categorisation in STATS19

Factoring for unknown goods vehicle weights

In STATS19 there are four vehicle types relating to goods vehicles:

- 19. Van/Goods vehicle 3.5 tonnes maximum gross weight (mgw) and under
- 20. Goods vehicle over 3.5 tonnes and under 7.5 tonnes mgw
- 21. Goods vehicle 7.5 tonnes mgw and over
- 98. Goods vehicle – unknown weight

Category 19 matches with the N1 category and categories 20 and 21 match with N2N3 categories. To ensure that as many casualties from STATS19 were included in the target populations, the number of casualties in collisions involving a goods vehicle with unknown weight (category 98) were split amongst the N1 and N2N3 categories according to the ratio of casualties in these collisions.

Overall, approximately 1% of casualties were in collisions involving a goods vehicle of unknown weight. The correction factors shown in Table 53 give that the target populations for casualties in N1 and N2N3 collisions need to be increased by 3.8% for fatalities, 5.3% for serious and 6.6% for slight based on the collisions involving vehicles with unknown weights (Nunk).

Table 53: Number of casualties in goods vehicle collisions and factoring for unknowns (2016 to 2019, 2021)

	Values	Nunk	N1	N2N3
All casualties in collisions involving	**Killed**	84	957	1245
	Serious (adjusted)	1,007	13,331	5,530
	Slight (adjusted)	5,918	66,115	23,397
Factored to account for Nunk	**Killed**	–	993.5	1,292.5
	Serious (adjusted)	–	14,042.7	5,825.3
	Slight (adjusted)	–	70,486.1	24,943.9
Adjustment factors	**Killed**	**–**	1.0381	1.0381
	Serious (adjusted)	**–**	1.0534	1.0534
	Slight (adjusted)	**–**	1.0661	1.0661

Factoring for target populations that involved analysis of contributory factors

Some of the definitions of target populations are based on the contributory factors recorded as part of STATS19 (for example DAW is those casualties in collisions where fatigue was recorded as a contributory factor). However, not all collisions are attended by the police and have contributory factors recorded.

Therefore, the target populations based on these data will under-report the number of casualties. It was therefore assumed that those collisions where the contributory factors were not known had the same proportion of each factor.

Table 54 shows the number of casualties of each severity in collisions by vehicle of interest and those with and without contributory factors recorded. This shows, for example that 86% of fatalities in collisions involving an M1 vehicle were attended by the police and had contributory factors recorded. Therefore, any target population based on contributory factors needs increasing by a factor of 1.161 or 16.1% increase. For all vehicles of interest, the factors are higher for less severe casualties, reflecting that a higher proportion of less severe collisions are not attended by the police.

Table 54: Number of casualties in collisions by vehicle type attended by the police with contributory factors recorded and adjustment factor (2016 to 2019, 2021)

Collisions involving	Severity	Casualties in collisions attended by police with CFs	All casualties in collisions	% attended by police with CFs	Adjustment factor
M1	**Killed**	5,827	6,765	86%	1.161
	Serious (adj.)	98,882	120,599	82%	1.220
	Slight (adj.)	408,361	580,344	70%	1.421
M2M3	**Killed**	275	322	85%	1.171
	Serious (adj.)	3,716	4,759	78%	1.281
	Slight (adj.)	18,865	27,079	70%	1.435
N1	**Killed**	851	957	89%	1.125
	Serious (adj.)	11,150	13,331	84%	1.196
	Slight (adj.)	48,359	66,115	73%	1.367
N2N3	**Killed**	1,080	1,245	87%	1.153
	Serious (adj.)	4,769	5,530	86%	1.160
	Slight (adj.)	18,175	23,397	78%	1.287

Other factoring

Distraction and fatigue are contributory factors that are assumed to be substantially under-reported in national collision statistics because it is difficult to determine by police. It is therefore proposed to correct the STATS19 target population extracts for ADW and DAW by fixed factors to account for this under-reporting.

In-depth research on the real prevalence of distraction in national collisions is not available, but figures quoted in the pre-amble to the relevant European regulation estimate that distraction is a contributory factor in 10% to 30% of road collisions in Europe (see Appendix C.2.3). It is proposed to use the mid-value of this range (20%) as best available estimate for the actual prevalence of distraction in road collisions in GB. The STATS19 extract highlights only 3.9% of road casualties as being contributed to by distraction. The proposed correction factor for under-reporting of distraction therefore is 5.0428 (20%/3.966054%).

Research shows that fatigue can be estimated to be a contributory factor in 20% of road collisions (see Appendix C.2.3). The STATS19 extract highlights only 1.4% of road casualties as being contributed to by fatigue. The proposed correction factor for under-reporting of fatigue therefore is 13.8520 (20%/1.443838%).

The STATS19 estimates were therefore corrected with the following factors:

- ADW: 5.0428
- DDAW: 13.8520

The same factors were used for all severities and all vehicle types as there was no evidence for an alternative.

Combined correction factors

The factors for each target population (vehicle category, technology and severity) were combined by multiplying the relevant factors. For example, target populations for N1 vehicles involving contributory factors have both the Nunk factor and the CF factor applied.

Note that for ADW and DAW the factors above were applied and not the CF factors.

Table 55: Adjustment factors for each vehicle category, technology and severity

Technology	Vehicle category	Killed	Serious	Slight
ADW	M1	5.042800	5.042800	5.042800
	M2M3	5.042800	5.042800	5.042800
	N1	5.235168	5.312167	5.376172
	N2N3	5.235168	5.312167	5.376172
AIF	M1	1.160975	1.219635	1.421152
	M2M3	1.195556	1.292417	1.455053
	N1	1.167458	1.259389	1.457573
	N2N3	1.196753	1.221482	1.372429
BSI	M2M3	1.000000	1.000000	1.000000
	N2N3	1.038147	1.053416	1.066109
DAW	M1	13.852000	13.852000	13.852000
	M2M3	13.852000	13.852000	13.852000
	N1	14.380414	14.591921	14.767736
	N2N3	14.380414	14.591921	14.767736
DIV	M2M3	1.000000	1.000000	1.000000
	N2N3	1.038147	1.053416	1.066109
EBC	M1	1.000000	1.000000	1.000000
	N1	1.038147	1.053416	1.066109
EBP	M1	1.000000	1.000000	1.000000
	N1	1.038147	1.053416	1.066109
EBV	M1	1.000000	1.000000	1.000000
	N1	1.038147	1.053416	1.066109

Technology	Vehicle category	Killed	Serious	Slight
EDR	M1	1.000000	1.000000	1.000000
	M2M3	1.000000	1.000000	1.000000
	N1	1.038147	1.053416	1.066109
	N2N3	1.038147	1.053416	1.066109
ELK	M1	1.000000	1.000000	1.000000
	N1	1.038147	1.053416	1.066109
ESS	M1	1.160975	1.219635	1.421152
	M2M3	1.195556	1.292417	1.455053
	N1	1.167458	1.259389	1.457573
	N2N3	1.196753	1.221482	1.372429
FFI	M1	1.000000	1.000000	1.000000
	N1	1.038147	1.053416	1.066109
FOI	N1	1.038147	1.053416	1.066109
ISA	M1	1.000000	1.000000	1.000000
	M2M3	1.000000	1.000000	1.000000
	N1	1.038147	1.053416	1.066109
	N2N3	1.038147	1.053416	1.066109
MOI	M2M3	1.000000	1.000000	1.000000
	N2N3	1.038147	1.053416	1.066109
PSI	M1	1.000000	1.000000	1.000000
	N1	1.038147	1.053416	1.066109
PWI	M1	1.000000	1.000000	1.000000
	N1	1.038147	1.053416	1.066109
RMA	M1	1.000000	1.000000	1.000000
	M2M3	1.000000	1.000000	1.000000
	N1	1.038147	1.053416	1.066109
	N2N3	1.038147	1.053416	1.066109
TPM	M2M3	1.195556	1.292417	1.455053
	N1	1.167458	1.259389	1.457573
	N2N3	1.196753	1.221482	1.372429

C.5.3 Collision constants

STATS19 data for 2012 to 2019 and 2021 was used to calculate the average number of casualties by severity per collision severity. This is used in the model to estimate the number of collisions based on the number of casualties. Table 56 shows the average number of casualties by severity for each collision severity.

Table 56: Average number of casualties per collision (STATS19 adjusted severities, 2012 to 2019, 2021)

Collision severity	Collisions		Killed	Serious	Slight	Total
Fatal	8,174	**Number of casualties**	8,679	2,624	2,566	13,869
		Casualties per collision	1.06	0.32	0.31	1.70
Serious	132,922	**Number of casualties**	–	143,721	59,829	203,550
		Casualties per collision	–	1.08	0.45	1.53
Slight	466,765	**Number of casualties**	–	–	576,922	576,922
		Casualties per collision	–	–	1.24	1.24
Total	**607,861**	**Number of casualties**	**8,679**	**146,344**	**639,318**	**794,341**
		Casualties per collision	**0.01**	**0.24**	**1.05**	**1.31**

On average, 1.06 road users are killed in a fatal collision; the vast majority have a single fatality, but a small number of fatal collisions involve multiple fatalities. A fatal collision also includes, on average 0.32 seriously injured casualties and 0.31 slightly injured casualties.

The number of collisions also needs to be split by road type (because the damage-only incidents per injury collision have different values for each road type – see Table 58). Table 57 gives, for each collision severity, the number and proportion of collisions by road type.

Table 57: Number and proportion of collisions by road type and severity (STATS19 adjusted severities; 2012 to 2019, 2021; proportion of collisions does not include unknowns)

	Road type	Fatal collision	Serious collision	Slight collision
Number of collisions	Motorway	448	3,950.6	17,868.4
	Rural road	4,730	48,939.1	128,869.9
	Urban road	2,994	79,997.6	319,948.4
	Total*	**8,174**	**132,922**	**466,765**
Proportion of collisions	Motorway	0.05482	0.02973	0.03829
	Rural road	0.57881	0.36828	0.27614
	Urban road	0.36637	0.60200	0.68557
	Total	**1**	**1**	**1**

*Includes a small number of collisions with unknown road type

The average number of damage-only collisions per injury collision from the TAG data book (Department for Transport, 2023) is shown in Table 58. This is based on data from insurance companies (Simpson & O'Reilly, 1994)and therefore is applied based on factored data from under-reporting in STATS19.

Table 58: Average damage-only collisions per PIA (TAG data book)

Road type	Estimated damage-only collisions per injury collision
Urban	17.7
Rural	7.8
Motorway	7.6

C.6 Technology effectiveness data

C.6.1 Casualty impacts

Technology effectiveness factors for preventing casualties and corresponding target population descriptions (to enable GB collision data analysis) for the vehicle safety technologies were extracted from available literature. The sources available from the rapid evidence assessment (Appendix C.2.2) and from the EU CBA (Seidl M, 2017) were critically appraised based on the scoring criteria set out in Table 59 below.

Table 59: Appraisal criteria for literature sources

Score	Relevance of studied technology	Relevance of geographic location	Type of study	Statistically significant results	Peer reviewed source
0	only indirectly related	non-European	prospective study/simulation	not significant	non-peer reviewed publication by generalists (e.g. general consultancy report)
1	basic functionality matches	Europe or mixed including Europe	retrospective real-world study	marginally significant	non-peer reviewed publication by expert researchers in the field
2	exact match	GB/UK	meta-analysis	significant	peer reviewed publication

Typically, the highest scoring source was selected except when other criteria (e.g. more suitable split of the reported results by injury severity) made another study more preferable.

From the selected source, safety effectiveness values were extracted. For the sensitivity analysis, additional high and low estimates for each parameter were derived by applying an uncertainty margin based on the steps outlined below:

1. Assess source quality as: Low (score 0-3), medium (score 4-6), high (score 7-10)
2. Based on source quality, vary estimates by: ±20% (low), ±10% (medium), ±5% (high)
3. Reduce by one stage if results are applied to a non-studied vehicle category (e.g. study is on M1, but results are applied to N1)

The corresponding target population descriptions to these effectiveness values were extracted from the same sources.

The literature sources selected for application based on this method are listed in Table 60.

Table 60: Literature sources selected for extraction of safety effectiveness values and target population descriptions

Technology	Literature source	Source updated from EU cost-benefit assessment?
ADW	No suitable studies identified (expert estimate)	No
AIF	(Martino, Sitran, & Rosa, 2014)	Yes
BSI	(Barrow, et al., 2017)	No
DAW	(Euro NCAP, 2011)	No
DIV	(Barrow, et al., 2017)	No
EBC	(Kullgren, Amin, & Tingvall, 2023)	Yes
EBP	(Cicchino, Effects of automatic emergency braking systems on pedestrian crash risk, 2022)	Yes
EBV	(Cicchino, Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates, 2017)	Yes
EDR	No suitable studies identified (expert estimate)	No
ELK	(Sternlund, Strandroth, Rizzi, Lie, & Tingvall, 2017) and (Cicchino, Effects of lane departure warning on police-reported crash rates, 2018)	No
ESS	No suitable studies identified (expert estimate)	No
FFI	(Edwards, et al., 2013)	No
FOI	(Farmer, 2005)	Yes
ISA	(Lai, Carsten, & Tate, 2012)	Yes
MOI	(Barrow, et al., 2017)	No
PSI	(Billot, Coulot, Zeitouni, Adalian, & Chauvel, 2013)	No
PWI	No suitable studies identified (TRL calculations)	No
RMA	(ACEA, 2017) and (Keall, Fildes, & Newstead, 2017)	No
TPM	No suitable studies identified (expert estimate)	No

The effectiveness estimates extracted from these sources are summarised in Table 61. The percentages given apply in relation to the target populations defined in Table 50, Appendix C.5.2.1. Note that the published effectiveness estimates for ISA were reduced in order to correct for increased baseline speed limit compliance in present times compared to the year 2004, when the underlying trial data was collected. Depending on the vehicle category, this reduced the effect to between 83% and 98% of the literature values.

Table 61: Safety technology effectiveness: Percent reduction in casualty rates within target population by each technology per vehicle category, casualty severity and sensitivity range

Vehicle category	Severity	Sensitivity range	ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
M1	Killed	High	20.04	23.52	n/a	20.04	n/a	22.05	31.50	58.80	2.40	55.65	30.00	10.67	n/a	18.00	n/a	59.40	2.39	35.70	n/a
M1	Killed	Medium	16.70	19.60	n/a	16.70	n/a	21.00	30.00	56.00	2.00	53.00	25.00	9.70	n/a	16.36	n/a	54.00	1.99	34.00	n/a
M1	Killed	Low	13.36	15.68	n/a	13.36	n/a	19.95	28.50	53.20	1.60	50.35	20.00	8.73	n/a	14.72	n/a	48.60	1.59	32.30	n/a
M1	Serious	High	20.04	23.52	n/a	20.04	n/a	22.05	31.50	58.80	2.40	40.43	36.00	14.41	n/a	12.17	n/a	59.40	1.18	35.70	n/a
M1	Serious	Medium	16.70	19.60	n/a	16.70	n/a	21.00	30.00	56.00	2.00	38.50	30.00	13.10	n/a	11.07	n/a	54.00	0.98	34.00	n/a
M1	Serious	Low	13.36	15.68	n/a	13.36	n/a	19.95	28.50	53.20	1.60	36.58	24.00	11.79	n/a	9.96	n/a	48.60	0.78	32.30	n/a
M1	Slight	High	20.04	23.52	n/a	20.04	n/a	22.05	31.50	58.80	1.20	40.43	24.00	0.00	n/a	6.35	n/a	0.00	0.00	35.70	n/a
M1	Slight	Medium	16.70	19.60	n/a	16.70	n/a	21.00	30.00	56.00	1.00	38.50	20.00	0.00	n/a	5.77	n/a	0.00	0.00	34.00	n/a
M1	Slight	Low	13.36	15.68	n/a	13.36	n/a	19.95	28.50	53.20	0.80	36.58	16.00	0.00	n/a	5.20	n/a	0.00	0.00	32.30	n/a
M2M3	Killed	High	20.04	23.52	47.64	20.04	3.48	n/a	n/a	n/a	2.40	n/a	30.00	n/a	n/a	15.48	47.64	n/a	n/a	46.68	9.96
M2M3	Killed	Medium	16.70	19.60	39.70	16.70	2.90	n/a	n/a	n/a	2.00	n/a	25.00	n/a	n/a	14.07	39.70	n/a	n/a	38.90	8.30
M2M3	Killed	Low	13.36	15.68	31.76	13.36	2.32	n/a	n/a	n/a	1.60	n/a	20.00	n/a	n/a	12.66	31.76	n/a	n/a	31.12	6.64
M2M3	Serious	High	20.04	23.52	48.00	20.04	3.60	n/a	n/a	n/a	2.40	n/a	36.00	n/a	n/a	10.47	48.00	n/a	n/a	46.68	9.96
M2M3	Serious	Medium	16.70	19.60	40.00	16.70	3.00	n/a	n/a	n/a	2.00	n/a	30.00	n/a	n/a	9.52	40.00	n/a	n/a	38.90	8.30
M2M3	Serious	Low	13.36	15.68	32.00	13.36	2.40	n/a	n/a	n/a	1.60	n/a	24.00	n/a	n/a	8.57	32.00	n/a	n/a	31.12	6.64
M2M3	Slight	High	20.04	23.52	48.00	20.04	3.60	n/a	n/a	n/a	1.20	n/a	24.00	n/a	n/a	5.46	48.00	n/a	n/a	46.68	9.96
M2M3	Slight	Medium	16.70	19.60	40.00	16.70	3.00	n/a	n/a	n/a	1.00	n/a	20.00	n/a	n/a	4.97	40.00	n/a	n/a	38.90	8.30
M2M3	Slight	Low	13.36	15.68	32.00	13.36	2.40	n/a	n/a	n/a	0.80	n/a	16.00	n/a	n/a	4.47	32.00	n/a	n/a	31.12	6.64
N1	Killed	High	20.04	23.52	n/a	20.04	n/a	23.10	33.00	61.60	2.40	58.30	30.00	10.67	49.50	18.35	n/a	59.40	2.39	35.70	8.30
N1	Killed	Medium	16.70	19.60	n/a	16.70	n/a	21.00	30.00	56.00	2.00	53.00	25.00	9.70	45.00	16.68	n/a	54.00	1.99	34.00	6.64
N1	Killed	Low	13.36	15.68	n/a	13.36	n/a	18.90	27.00	50.40	1.60	47.70	20.00	8.73	40.50	15.01	n/a	48.60	1.59	32.30	9.96
N1	Serious	High	20.04	23.52	n/a	20.04	n/a	23.10	33.00	61.60	2.40	42.35	36.00	14.41	49.50	12.41	n/a	59.40	1.18	35.70	8.30
N1	Serious	Medium	16.70	19.60	n/a	16.70	n/a	21.00	30.00	56.00	2.00	38.50	30.00	13.10	45.00	11.28	n/a	54.00	0.98	34.00	6.64
N1	Serious	Low	13.36	15.68	n/a	13.36	n/a	18.90	27.00	50.40	1.60	34.65	24.00	11.79	40.50	10.15	n/a	48.60	0.78	32.30	9.96
N1	Slight	High	20.04	23.52	n/a	20.04	n/a	23.10	33.00	61.60	1.20	42.35	24.00	0.00	0.00	6.48	n/a	0.00	0.00	35.70	8.30
N1	Slight	Medium	16.70	19.60	n/a	16.70	n/a	21.00	30.00	56.00	1.00	38.50	20.00	0.00	0.00	5.89	n/a	0.00	0.00	34.00	6.64
N1	Slight	Low	13.36	15.68	n/a	13.36	n/a	18.90	27.00	50.40	0.80	34.65	16.00	0.00	0.00	5.30	n/a	0.00	0.00	32.30	9.96
N2N3	Killed	High	20.04	23.52	43.67	20.04	3.19	n/a	n/a	n/a	2.40	n/a	30.00	n/a	n/a	16.75	43.67	n/a	n/a	42.79	9.96
N2N3	Killed	Medium	16.70	19.60	39.70	16.70	2.90	n/a	n/a	n/a	2.00	n/a	25.00	n/a	n/a	15.23	39.70	n/a	n/a	38.90	8.30
N2N3	Killed	Low	13.36	15.68	35.73	13.36	2.61	n/a	n/a	n/a	1.60	n/a	20.00	n/a	n/a	13.71	35.73	n/a	n/a	35.01	6.64
N2N3	Serious	High	20.04	23.52	44.00	20.04	3.30	n/a	n/a	n/a	2.40	n/a	36.00	n/a	n/a	11.33	44.00	n/a	n/a	42.79	9.96
N2N3	Serious	Medium	16.70	19.60	40.00	16.70	3.00	n/a	n/a	n/a	2.00	n/a	30.00	n/a	n/a	10.30	40.00	n/a	n/a	38.90	8.30
N2N3	Serious	Low	13.36	15.68	36.00	13.36	2.70	n/a	n/a	n/a	1.60	n/a	24.00	n/a	n/a	9.27	36.00	n/a	n/a	35.01	6.64
N2N3	Slight	High	20.04	23.52	44.00	20.04	3.30	n/a	n/a	n/a	1.20	n/a	24.00	n/a	n/a	5.91	44.00	n/a	n/a	42.79	9.96
N2N3	Slight	Medium	16.70	19.60	40.00	16.70	3.00	n/a	n/a	n/a	1.00	n/a	20.00	n/a	n/a	5.37	40.00	n/a	n/a	38.90	8.30
N2N3	Slight	Low	13.36	15.68	36.00	13.36	2.70	n/a	n/a	n/a	0.80	n/a	16.00	n/a	n/a	4.84	36.00	n/a	n/a	35.01	6.64

C.6.2 Environmental and journey time impacts

Significant impacts on fuel/energy consumption, emissions or journey times are expected from only two of the technologies being considered in this study. These are TPM, as there is strong evidence that under-inflation causes significant increases in fuel consumption and tyre wear, leading to increased particulate emissions; and ISA, as there is a well-established relationship between speed, drive cycle and fuel consumption, and journey time might be impacted by limited speeds.

However, while the studies found during the Rapid Evidence Review provided quantitative evidence of impacts, the wide ranges in impacts found do not lend themselves to direct derivation of all of the technology effectiveness factors required for the impact model. In many cases results were inclusive and likely to be dependent upon a range of other factors. The factors presented below were therefore chosen for the purpose of sensitivity testing, so that the overall scale of potential environmental impacts can be compared with the casualty reduction benefits, using plausible ranges for maximum (Optimistic scenario) and minimum (Pessimistic scenario) impacts.

C.6.2.1 ISA Effectiveness Factors

As reported in Appendices C.2.4 and C.2.5, the evidence for environmental impacts of ISA is mixed. (Lai, Carsten, & Tate, 2012) was identified in Appendix C.6.1 as the strongest source for assessing the casualty impacts of ISA in GB, and the same considerations apply to environmental impacts, so this source was the primary source used to inform the proposed technology effectiveness factors for environmental impacts. The literature review (Ryan, 2019) was used for journey time impacts and was also considered for identifying maximum and minimum limits for the proposed ranges of environmental impacts.

Fuel consumption, CO_2e, electricity consumption

(Lai, Carsten, & Tate, 2012) based their impact estimates on previous work by (Carsten O F. M., 2008) with predicted CO_2 emission savings on 70 mph roads of 3.4% for voluntary ISA (i.e. limiting but overridable systems) and 5.8% for mandatory (limiting and not overridable systems). A value of 3.0% was used for the medium effectiveness factor to represent a slight reduction based on the fact that the fleet will also comprise advisory ISA systems, which can be assumed to have a reduced effect. Although mandatory ISA is not currently proposed, the value for the forecast savings was taken effectiveness factor for the high sensitivity range, representing a best case in which compliance with voluntary ISA becomes very high so that its impact tends towards that of a mandatory system. As heavy vehicles are already speed limited, ISA would have no impact on them on 60 or 70 mph roads, so the technical effectiveness of 0% is set for high, medium and low sensitivity ranges on those roads. Ryan found studies reporting zero savings on high-speed roads when congestion is high, so the low sensitivity range was set at 0%.

For lower speed roads (non-70 mph), the Lai et al. report that the impact on fuel consumption is variable and small, and these were therefore not included in their model. Hence a value of 0% is proposed for the medium effectiveness factor for these roads with a range of ±0.5% for sensitivity testing. Note, as 'A roads' are predominantly 60 mph limited single carriageways, these were given the same technology effectiveness as minor roads.

eVs and ICE vehicles have some differences in their energy consumption variation with speed and traffic conditions; in particular regenerative braking improves the energy efficiency of eVs in congested traffic. However, in the absence of specific evidence of how ISA affects eVs, for modelling purposes the eVs were given the same effectiveness factors as the ICE vehicles.

NOx and PM

(Lai, Carsten, & Tate, 2012) assume no changes in tailpipe emissions, and no strong evidence of impacts on tailpipe emissions was reported elsewhere, so the medium effectiveness factor was set to 0% for all vehicle and road combinations. No specific evidence of impacts on tyre or brake wear were identified, so the medium effectiveness of 0% was also specified for these sources of particulate emission. For both NOx and PM emissions, a smoother driving style would be expected to reduce emissions, which could be encouraged by ISA. On the other hand, if drivers respond to ISA by trying to accelerate to the maximum, then there could be a contrary effect. For this reason, in the absence of quantitative data, sensitivity testing ranges for of ±0.5% for high and low ranges were proposed.

Journey time

By limiting maximum speeds, ISA could increase some journey times; however, by encouraging smoother driving, and reducing the speed differential between the fastest and slowest vehicles, congestion could be reduced, and journey time reliability improved. Findings on this topic were mixed and both outcomes were reported in the studies considered in the evidence review. Therefore the medium effectiveness factor assumes no impact on journey time and is set to 0%.

(Lai, Carsten, & Tate, 2012) did not include journey time or reliability impacts in their cost-benefit analysis. (Ryan, 2019) reports that most studies found an increase in journey time; however, also reporting opposite results. A UK-based study reported increases of 4.3% in built-up areas, 0.4% in non-built-up areas and no effect on motorways. These values are used as negative effectiveness values for the low sensitivity range. In absence of further firm quantitative evidence and in light of opposite findings reported, the same values as journey time decreases are used for the high sensitivity range.

C.6.2.2 TPM Effectiveness Factors

As TPM is already mandatory for vehicle category M1, the consideration of effectiveness factors applies to categories M2 & M3, N1 and N2 & N3 only.

No specific trials of the environmental impact of TPM were found; however, the studies found in the rapid evidence review show that low tyre pressure can cause significant increases in fuel consumption and tyre wear, so TPM would be expected to create benefits in fuel/energy consumption (and hence CO_2 emissions), and also in particle emissions from tyre wear. A quantitative estimate of the effectiveness factors would require data on the relationship between under-inflation and fuel consumption and tyre wear, the prevalence of under-inflation in the fleet and information on the extent to which users would respond to TPM warnings. In the absence of this information, an attempt was made to propose technology effectiveness factors with plausible range of values for the purpose of sensitivity analysis.

A range of figures can be found for the relationship between tyre pressure and fuel consumption. For example, (Marton Z, 2014) found that under-inflation by 17% can increase fuel consumption by 2%. This is similar to the average level of under-inflation found in the Goodyear tires survey (Pölös, 2022), in which three-quarters of vehicles had at least one under-inflated tyre, but it is not further quantified how many tyres per vehicle were underinflated on average. Broadly comparable figures were reported in other sources identified in the rapid evidence review. No specific evidence was found concerning differences between different road types or vehicle categories. An effectiveness factor of 0.5% is proposed for the high sensitivity scenario representing a scenario where a quarter of all vehicle tyres would be underinflated without TPM by about the level quoted by Marton as having a 2% impact, and TPM would encourage all users to correct tyre pressure. For sensitivity testing, the medium effectiveness factor assumes half that effect, i.e. 0.25%, and the low sensitivity range assumes no effect, i.e. 0%.

The increased tyre wear reported with underinflated tyres would be expected to result in an increase in emissions of suspended particles, although no specific information was found on the exact relationship. On the assumption that the PM emission rate from tyre wear will be inversely proportional to the lifespan, then a 20% reduction in lifespan as reported by (Volvo Trucks, 2020) would result in a 20% increase in emissions. For the high scenario, using the same assumptions as above (a quarter of all tyres being underinflated and TPM being fully effective), a reduction of 5% is proposed. For sensitivity testing, the medium effectiveness factor assumes half that effect, i.e. 2.5%, and the low sensitivity range assumes no effect, i.e. 0%.

Appendix D Detailed results

This appendix contains summary tables of results from the Clustered Impact Appraisal Model (CIAM) and the Economic Appraisal Model (EAM) as well as detailed descriptions of the secondary impacts identified. Some of the results presented here are not contained in the main body, including detailed results for technology packages in the Optimistic and Pessimistic scenarios.

Preceding Appendix B describes the structure of the models developed to quantify and monetise the primary impacts and the calculation methods implemented. Appendix C describes the data that was input into CIAM (such as baseline casualty numbers, technology effectiveness estimates and cost estimates) to calculate impacts for the present study.

D.1 Technology packages: Cost effectiveness and primary impacts

All quantified impacts and BCRs for the Central Estimate, Optimistic and Pessimistic scenario are summarised below for each technology package.

D.1.1 All technologies (TP1)

Table 62: TP1, Central Estimate: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	10,097	1,006.9	72.8	4.8	143.0	0.0	0.0	18,832.7	40,482.0	502.4	0.0
M2M3	1,764	19.2	1.2	42.0	9.0	0.0	4.7	3,394.1	0.0	15.3	0.0
N1	930	144.4	8.9	3.5	73.1	0.0	41.0	27,259.7	489.1	164.3	0.0
N2N3	2,807	189.1	11.5	8.7	79.3	0.0	98.7	30,063.7	0.0	83.7	0.0
Total	**14,406**	**1,365.4**	**94.5**	**5.4**	**304.3**	**0.0**	**144.4**	**79,550.3**	**40,971.2**	**765.7**	**0.0**

Table 63: TP1, Optimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	10,488	605.3	45.8	11.3	327.8	56.8	31.5	42,967.5	93,061.1	1,077.7	157.8
M2M3	1,983	11.9	0.6	91.0	32.6	18.0	12.4	12,353.8	0.0	54.2	13.2
N1	977	87.0	5.6	10.8	159.1	49.1	91.0	59,315.6	1,090.7	348.2	31.2
N2N3	3,083	117.0	5.8	18.1	182.5	81.5	237.3	69,135.6	0.0	191.4	18.7
Total	**15,154**	**824.7**	**57.8**	**12.7**	**701.9**	**205.4**	**372.3**	**183,772.5**	**94,151.8**	**1,671.5**	**220.7**

Table 64: TP1, Pessimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	7,098	1,804.8	111.4	1.0	-48.4	-52.8	-29.0	-6,195.1	-13,911.4	-99.2	-146.1
M2M3	1,150	32.1	2.0	11.5	-14.7	-17.6	-3.2	-5,566.9	0.0	-23.6	-12.9
N1	647	279.3	13.5	0.0	-15.5	-45.3	-8.3	-5,760.4	-125.7	-25.2	-26.7
N2N3	1,858	345.2	18.2	2.3	-23.7	-79.3	-41.5	-8,998.9	0.0	-23.9	-18.3
Total	**10,012**	**2,470.8**	**145.3**	**1.1**	**-102.3**	**-194.9**	**-82.0**	**-26,521.2**	**-14,037.1**	**-171.9**	**-204.0**

D.1.2 All technologies excluding ISA (TP2)

Table 65: TP2, Central Estimate: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	6,897	845.0	28.5	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	815	17.0	0.6	23.1	9.0	0.0	4.7	3,394.1	0.0	15.3	0.0
N1	550	121.0	3.4	2.5	17.7	0.0	41.0	6,599.1	134.5	37.4	0.0
N2N3	1,289	168.6	5.4	5.0	79.3	0.0	98.7	30,063.7	0.0	83.7	0.0
Total	**9,062**	**1,156.7**	**37.9**	**4.3**	**106.0**	**0.0**	**144.4**	**40,057.0**	**134.5**	**136.4**	**0.0**

Table 66: TP2, Optimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	7,080	506.4	18.4	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	964	11.4	0.4	41.3	17.9	0.0	9.4	6,781.3	0.0	30.7	0.0
N1	572	72.7	2.2	4.7	35.2	0.0	81.8	13,086.3	266.8	74.0	0.0
N2N3	1,444	112.1	3.9	9.1	158.7	0.0	197.0	60,117.8	0.0	167.4	0.0
Total	**9,496**	**706.0**	**25.0**	**7.6**	**211.7**	**0.0**	**288.1**	**79,985.3**	**266.8**	**272.0**	**0.0**

Table 67: TP2, Pessimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	4,908	1,550.9	40.8	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	496	28.7	1.0	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N1	385	242.6	4.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N2N3	825	312.9	8.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**6,310**	**2,143.4**	**55.2**	**1.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

D.1.3 UNECE regulations only (TP3)

Table 68: TP3, Central Estimate: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	4,407	524.3	23.0	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	627	9.1	0.6	29.9	9.0	0.0	4.7	3,394.1	0.0	15.3	0.0
N1	383	75.4	2.6	2.9	17.7	0.0	41.0	6,599.1	134.5	37.4	0.0
N2N3	495	97.1	5.4	3.5	79.3	0.0	98.7	30,063.7	0.0	83.7	0.0
Total	**5,667**	**710.6**	**31.7**	**4.4**	**106.0**	**0.0**	**144.4**	**40,057.0**	**134.5**	**136.4**	**0.0**

Table 69: TP3, Optimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	4,521	333.5	15.0	7.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	684	6.0	0.4	49.9	17.9	0.0	9.4	6,781.3	0.0	30.7	0.0
N1	414	49.4	1.8	5.1	35.2	0.0	81.8	13,086.3	266.8	74.0	0.0
N2N3	545	64.2	3.9	6.7	158.7	0.0	197.0	60,117.8	0.0	167.4	0.0
Total	**5,891**	**455.3**	**21.2**	**7.4**	**211.7**	**0.0**	**288.1**	**79,985.3**	**266.8**	**272.0**	**0.0**

Table 70: TP3, Pessimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	3,145	1,035.3	33.3	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	353	13.7	1.0	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N1	276	173.0	4.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N2N3	323	190.2	8.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**3,943**	**1,417.5**	**46.9**	**1.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

D.1.4 Regulation based on pessimistic cost effectiveness (TP4)

Table 71: TP4, Central Estimate: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	5,637	562.2	20.8	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	747	11.2	0.2	32.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N1	384	75.4	2.3	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N2N3	1,132	99.3	2.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**7,460**	**751.0**	**25.3**	**5.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Table 72: TP4, Optimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	5,779	325.7	13.1	9.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	884	7.4	0.2	57.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N1	403	43.6	1.4	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N2N3	1,274	65.2	1.5	12.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**7,830**	**443.9**	**16.2**	**9.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Table 73: TP4, Pessimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	4,014	924.0	33.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	455	17.9	0.3	12.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N1	266	123.9	3.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N2N3	718	165.9	2.3	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**5,180**	**1,235.9**	**39.3**	**2.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

D.1.5 Regulation based on pessimistic casualty effectiveness (TP5)

Table 74: TP5, Central Estimate: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	9,846	932.6	72.8	5.1	143.0	0.0	0.0	18,832.7	40,482.0	502.4	0.0
M2M3	1,706	15.6	1.0	49.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N1	858	126.6	8.9	3.7	55.4	0.0	0.0	20,664.1	354.7	126.9	0.0
N2N3	2,700	138.2	9.6	10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**13,943**	**1,217.1**	**92.4**	**5.7**	**198.3**	**0.0**	**0.0**	**39,496.8**	**40,836.8**	**629.3**	**0.0**

Table 75: TP5, Optimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	10,211	561.9	45.8	11.9	327.8	56.8	31.5	42,967.5	93,061.1	1,077.7	157.8
M2M3	1,915	9.6	0.5	108.2	14.7	18.0	3.1	5,578.7	0.0	23.6	13.2
N1	905	76.3	5.6	11.4	123.9	49.1	9.3	46,245.1	824.1	274.3	31.2
N2N3	2,968	85.0	4.6	22.6	23.8	81.5	40.7	9,028.0	0.0	24.1	18.7
Total	**14,649**	**735.4**	**56.5**	**13.5**	**490.3**	**205.4**	**84.6**	**103,819.2**	**93,885.3**	**1,399.7**	**220.7**

Table 76: TP5, Pessimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	6,936	1,484.3	111.4	1.2	-48.4	-52.8	-29.0	-6,195.1	-13,911.4	-99.2	-146.1
M2M3	1,114	24.7	1.5	14.4	-14.7	-17.6	-3.2	-5,566.9	0.0	-23.6	-12.9
N1	594	201.4	13.5	0.0	-15.5	-45.3	-8.3	-5,760.4	-125.7	-25.2	-26.7
N2N3	1,784	226.4	14.1	3.4	-23.7	-79.3	-41.5	-8,998.9	0.0	-23.9	-18.3
Total	**9,703**	**1,943.1**	**140.6**	**1.3**	**-102.3**	**-194.9**	**-82.0**	**-26,521.2**	**-14,037.1**	**-171.9**	**-204.0**

D.1.6 Vulnerable road user protection (TP6)

Table 77: TP6, Central Estimate: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	5,681	593.9	67.6	4.0	143.0	0.0	0.0	18,832.7	40,482.0	502.4	0.0
M2M3	1,688	17.5	1.2	43.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N1	599	81.3	8.6	3.7	55.4	0.0	0.0	20,664.1	354.7	126.9	0.0
N2N3	2,692	171.1	11.5	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**9,741**	**869.1**	**89.0**	**5.2**	**198.3**	**0.0**	**0.0**	**39,496.8**	**40,836.8**	**629.3**	**0.0**

Table 78: TP6, Optimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	6,036	347.4	42.2	12.2	327.8	56.8	31.5	42,967.5	93,061.1	1,077.7	157.8
M2M3	1,894	10.8	0.6	94.6	14.7	18.0	3.1	5,578.7	0.0	23.6	13.2
N1	639	47.5	5.4	14.4	123.9	49.1	9.3	46,245.1	824.1	274.3	31.2
N2N3	2,948	105.9	5.8	18.0	23.8	81.5	40.7	9,028.0	0.0	24.1	18.7
Total	**10,441**	**514.9**	**54.1**	**14.3**	**490.3**	**205.4**	**84.6**	**103,819.2**	**93,885.3**	**1,399.7**	**220.7**

Table 79: TP6, Pessimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	3,894	1,008.5	105.6	0.1	-48.4	-52.8	-29.0	-6,195.1	-13,911.4	-99.2	-146.1
M2M3	1,103	30.1	2.0	11.6	-14.7	-17.6	-3.2	-5,566.9	0.0	-23.6	-12.9
N1	411	137.7	13.3	-0.8	-15.5	-45.3	-8.3	-5,760.4	-125.7	-25.2	-26.7
N2N3	1,788	299.1	18.2	2.6	-23.7	-79.3	-41.5	-8,998.9	0.0	-23.9	-18.3
Total	**6,633**	**1,484.0**	**139.3**	**0.5**	**-102.3**	**-194.9**	**-82.0**	**-26,521.2**	**-14,037.1**	**-171.9**	**-204.0**

D.1.7 Vehicle manipulation technologies (TP7)

Table 80: TP7, Central Estimate: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	4,998	502.7	18.4	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N1	329	67.1	2.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N2N3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**5,141**	**569.8**	**20.4**	**5.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Table 81: TP7, Optimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	5,013	317.4	11.6	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N1	342	42.4	1.3	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N2N3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**5,159**	**359.7**	**12.9**	**8.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Table 82: TP7, Pessimistic scenario: Cost effectiveness and primary impacts

	KSIs prevented 2025–2039	Fitment costs (£ million)	Repair / maintenance costs (£ million)	BCR	CO_2 prevented (kilo-tonnes)	NOx prevented (tonnes)	PM_{10} prevented (tonnes)	Diesel saved (thousand litres)	Petrol saved (thousand litres)	Electricity saved (million kWh)	Journey time saved (million hours)
M1	3,654	829.0	30.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2M3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N1	232	110.5	3.4	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N2N3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**3,759**	**939.5**	**33.4**	**2.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

D.2 Technology packages: Costs and benefits (Central Estimate)

The Central Estimates of aggregate present values of costs and benefits over the appraisal period and net present values (NPVs) are summarised below for each technology package.

Table 83: TP1, Central Estimate: Aggregate present values of costs and benefits over appraisal period and net present values (NPVs)

	Present value benefits (£ million)	Present value costs (£ million)	Net present values (£ million)
M1	5,236.4	1,079.8	4,156.6
M2M3	860.8	20.5	840.4
N1	541.8	153.3	388.5
N2N3	1,740.4	200.6	1,539.9
Total	**7,852.7**	**1,459.9**	**6,392.8**

Table 84: TP2, Central Estimate: Aggregate present values of costs and benefits over appraisal period and net present values (NPVs)

	Present value benefits (£ million)	Present value costs (£ million)	Net present values (£ million)
M1	3,714.5	873.5	2,841.0
M2M3	406.8	17.6	389.2
N1	316.8	124.4	192.4
N2N3	875.3	174.0	701.3
Total	**5,119.9**	**1,194.6**	**3,925.4**

Table 85: TP3, Central Estimate: Aggregate present values of costs and benefits over appraisal period and net present values (NPVs)

	Present value benefits (£ million)	Present value costs (£ million)	Net present values (£ million)
M1	2,433.9	547.3	1,886.5
M2M3	289.5	9.7	279.8
N1	223.8	78.0	145.8
N2N3	361.7	102.5	259.2
Total	**3,248.8**	**742.3**	**2,506.6**

Table 86: TP4, Central Estimate: Aggregate present values of costs and benefits over appraisal period and net present values (NPVs)

	Present value benefits (£ million)	Present value costs (£ million)	Net present values (£ million)
M1	3,226.8	582.9	2,643.9
M2M3	367.6	11.5	356.2
N1	232.2	77.7	154.5
N2N3	721.2	101.4	619.9
Total	**4,310.8**	**776.4**	**3,534.5**

Table 87: TP5, Central Estimate: Aggregate present values of costs and benefits over appraisal period and net present values (NPVs)

	Present value benefits (£ million)	Present value costs (£ million)	Net present values (£ million)
M1	5,123.7	1,005.4	4,118.3
M2M3	826.5	16.6	809.9
N1	499.0	135.5	363.5
N2N3	1,617.7	147.7	1,470.0
Total	**7,483.8**	**1,309.5**	**6,174.3**

Table 88: TP6, Central Estimate: Aggregate present values of costs and benefits over appraisal period and net present values (NPVs)

	Present value benefits (£ million)	Present value costs (£ million)	Net present values (£ million)
M1	2,665.8	661.5	2,004.3
M2M3	818.0	18.8	799.3
N1	333.2	89.8	243.3
N2N3	1,613.6	182.6	1,431.0
Total	**4,975.0**	**958.1**	**4,016.9**

Table 89: TP7, Central Estimate: Aggregate present values of costs and benefits over appraisal period and net present values (NPVs)

	Present value benefits (£ million)	Present value costs (£ million)	Net present values (£ million)
M1	2,875.0	521.1	2,353.9
M2M3	0.0	0.0	0.0
N1	197.0	69.1	127.9
N2N3	0.0	0.0	0.0
Total	**2,972.9**	**590.2**	**2,382.7**

D.3 All technologies (TP1): Central Estimate, Pessimistic and Optimistic scenarios compared

Comparing the Pessimistic and Optimistic scenarios with the Central Estimate demonstrated the possible range of outcomes. In terms of KSIs avoided all make useful contributions.

Table 90: Comparison of the KSIs avoided

	Pessimistic scenario	Central Estimate	Optimistic scenario
M1	7,098	10,097	10,488
M2M3	1,150	1,764	1,983
N1	647	930	977
N2N3	1,858	2,807	3,083
TOTAL	**10,012**	**14,406**	**15,154**

Inevitably the Pessimistic scenario generates a lower number of KSIs saved – just over 10,000 (about 70% of the Central Estimate) but the Optimistic scenario does not perform substantially better than the Central Estimate (see Table 90). Under the Pessimistic scenario approximately 667 KSIs per annum would be saved over the 15 years from 2025 to 2039.

Table 91: Comparison of the Pessimistic, Central and Optimistic BCRs

	Pessimistic scenario	Central Estimate	Optimistic scenario
M1	1.0	4.8	11.3
M2M3	11.5	42.0	91.0
N1	0.0	3.5	10.8
N2N3	2.3	8.7	18.1
TOTAL	**1.1**	**5.4**	**12.7**

In terms of the BCRs, the Pessimistic scenario performs 'low' with a BCR for the total just above one, although for M2M3 (buses and coaches) it is much higher (see Table 91). While the BCR for M2M3 remains high it is still substantially below that for both the Central Estimate and the Optimistic scenario. The BCRs for the Optimistic scenario can be attributed mainly to the lower costs involved since the casualties saved are similar to the Central Estimate. The BCRs for the Pessimistic scenario are poor due to the estimated higher costs involved as well as the low expectations of numbers of KSIs reduced. Nevertheless, some individual technologies do generate BCRs above one in the Pessimistic scenario.

D.4 Individual technologies: Pessimistic scenario results

An investigation of the results for the Pessimistic scenarios for individual technologies demonstrates that there are eight which generate a BCR > 1 (see Table 92): ADW, AIF, DAW, EBP, EBV, EDR, ELK and MOI (note that FFI has a BCR of just under 1, at 0.954).

ISA generates no positive or negative BCR under the Pessimistic scenario. This is because the four main components of the benefits calculated are: Safety, Environmental, Fuel & Energy, and Journey Time. Only safety has a positive benefit, the other three are negative (which is in line with the effectiveness input data entered into the CIAM, i.e. reflecting that emissions and fuel usage might go up and that journey times might increase). Furthermore, in the Pessimistic scenario fewer KSIs would be avoided applying ISA. The journey time increase appears to dwarf the other impact components for ISA.

Table 92: Killed and seriously injured (KSI) casualties prevented, benefit-cost ratios (BCRs), technology fitment costs, and repair and maintenance costs of individual technologies in the Pessimistic scenario

	KSIs prevented 2025–2039	BCR	Fitment costs (£ million)	Repair / maintenance costs (£ million)
ADW	575	1.3	281.9	0.0
AIF	97	4.3	11.2	0.0
BSI	89	0.7	54.9	4.8
DAW	493	3.3	76.9	0.0
DIV	20	0.2	58.0	0.0
EBC	367	0.5	268.5	23.6
EBP	726	1.0	269.7	24.8
EBV	1,419	3.8	261.3	26.8
EDR	261	1.9	60.3	0.0
ELK	1,257	1.0	542.7	58.3
ESS	7	0.5	11.2	0.0
FFI	317	1.0	87.4	0.0
FOI	37	0.3	31.0	0.0
ISA	3,796	0.0	524.9	144.3
MOI	401	6.3	30.1	2.6
PSI	57	0.1	263.4	0.0
PWI	14	0.1	79.0	0.0
RMA	238	0.8	138.1	14.4
TPM	2	0.0	25.7	0.0

D.5 Secondary impacts (qualitative appraisals)

While the CBA model quantified the dominant safety, environmental, journey time and cost impacts, this section will discuss secondary impacts, i.e. those which are of less importance and/or where sufficient data or valuations are unavailable to undertake a quantitative approach. The qualitative analysis is framed around the four main components of the appraisal summary table from TAG, i.e. economic, environmental, social and public accounts impacts.

For each secondary impact identified, indication is given as to which technologies it arises from, followed by a description of the impact and a qualitative appraisal on a seven-point scale of adverse, neutral or beneficial. The impacts described apply to each technology package that contains any of the technologies marked as relevant.

Where a secondary impact has relevance for the Public Sector Equality Duty (PSED), this will be stated in the text. The PSED requires public authorities, in carrying out their functions, to have due regard to the need to achieve the objectives set out under s149 of the Equality Act 2010, including to advance equality of opportunity between persons who share a protected characteristic and persons who do not share it. It will therefore be necessary to ensure that no adverse impacts of the introduction of the technologies disproportionately affect people with any of the nine protected characteristics that are defined in the Act: age, being pregnant or on maternity leave, disability, race including colour, nationality, ethnic or national origin, religion or belief, sex, sexual orientation, gender reassignment, and being married or in a civil partnership.

D.5.1 Economic impacts

Economic impacts capture the effects of the transport system on businesses.

D.5.1.1 Journey time reliability

ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
☑	☑	☑	☑	☑	☑	☑	☑	×	☑	☑	×	×	☑	☑	×	×	☑	☑

Road traffic collisions and breakdown incidents require unplanned road or lane closures and therefore cause unpredictable delays, which can be substantial on routes with heavy traffic. Driver assistance and active safety technologies can prevent such incidents from occurring and therefore make journey times on the road network more predictable, in particular on arterial roads and motorways. Hauliers and other logistics companies will therefore be enabled to plan journeys more accurately, thereby using their available resources such as drivers and vehicles better. Other business sectors relying on accurate delivery time predictions will be enabled to operate more efficiently.

	Adverse			Neutral			Beneficial
	−3	−2	−1	0	+1	+2	+3
Appraisal						■	

D.5.1.2 Technological capabilities

ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
×	×	☑	×	×	☑	☑	☑	×	☑	×	×	×	☑	×	×	×	×	×

Some of the technologies can be regarded as enablers for automated driving because they provide some of the capabilities required to replace a driver, such as determining the applicable speed limit and reliably detecting other road users. Increased demand for these technologies will enable domestic vehicle manufacturers and the domestic supply chain to gain more expertise with these technological building blocks and thus enhance their technological capabilities in the area of automated driving.

	Adverse			Neutral			Beneficial
	−3	−2	−1	0	+1	+2	+3
Appraisal					■		

D.5.1.3 Resources for research

ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
×	×	×	×	×	×	×	×	☑	×	×	×	×	×	×	×	×	×	×

Vehicle and traffic safety research by public and private sector bodies helps improve road and vehicle design standards and driver training and enforcement. This work relies on studying real-world collisions to understand their causes, consequences and countermeasures. The quality of data collected by police and the in-depth accident study programme funded by the DfT would be enhanced by objective measurements of vehicle movement, driver actions and vehicle safety technology interventions before, during and immediately after a collision, which could be provided by EDR.

	Adverse			Neutral			Beneficial
	−3	−2	−1	0	+1	+2	+3
Appraisal						■	

D.5.2 Environmental impacts

Environmental impacts cover the effects of the transport system on the built and natural environment, and on people.

D.5.2.1 Traffic noise

ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
×	×	×	×	×	×	×	×	×	×	×	×	×	☑	×	×	×	×	☑

The noise generated by motor vehicles is influenced, inter alia, by the driving speed and tyre pressure. ISA could reduce traffic noise levels by helping reduce driving speeds overall and by smoothing traffic flow thereby reducing the number of vehicles accelerating with high engine load. TPM helps drivers maintain correct tyre pressure and could thereby eliminate underinflated tyres as a contributor to elevated traffic noise levels.

	Adverse			**Neutral**			**Beneficial**
	−3	−2	−1	0	+1	+2	+3
Appraisal					■		

D.5.2.2 Water pollution

ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	☑

Wear and tear of tyres releases plastic particles into the environment. Larger particles get deposited on the road surface and then partially transported by rainwater runoff into soils, sewers and surface waters, with the potential to harm flora and fauna. Correctly inflated tyres experience reduced wear compared to underinflated tyres, which is why TPM has the potential to reduce the amount of plastic particles entering water bodies.

	Adverse			**Neutral**			**Beneficial**
	−3	−2	−1	0	+1	+2	+3
Appraisal					■		

D.5.3 Social impacts

Social impacts cover the human experience of the transport system and its impact on social factors.

D.5.3.1 Journey time reliability

ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
☑	☑	☑	☑	☑	☑	☑	☑	×	☑	☑	×	×	☑	☑	×	×	☑	☑

Improved journey time reliability, as outlined in Appendix D.5.1.1, also has social impacts with most motorised road users benefiting from efficient use of their time. Commuters can be expected to experience the greatest impact because incidents in rush hour traffic typically cause the greatest delays. Apart from more efficient use of drivers' time, improved reliability could also contribute to reduced tension and anxiety experienced about journey times.

	Adverse			Neutral			Beneficial
	−3	−2	−1	0	+1	+2	+3
Appraisal						■	

D.5.3.2 Active travel

ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
☑	×	☑	☑	☑	☑	☑	×	×	×	×	×	×	☑	☑	×	☑	☑	×

Safety concerns can cause road users to refrain from using active travel modes, where they are unprotected, and choose motorised individual transport instead. Technologies which reduce the number of VRU collisions or mitigate their impacts could increase the perceived safety and thus reduce barriers to active travel which would have additional environmental benefits from reduced fuel and energy usage and also health benefits from physical activity. ISA in particular could also aid drivers in adhering to 20 mph speed limits in areas where they apply and reduce the need for some infrastructure changes, such as road humps.

	Adverse			Neutral			Beneficial
	−3	−2	−1	0	+1	+2	+3
Appraisal						■	

D.5.3.3 Crime

ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
×	☑	×	×	×	×	×	×	×	×	×	×	×	☑	×	×	×	×	×

While mandatory implementation of vehicle technologies cannot have a big impact on crime overall, two technologies could have a limited crime reducing effect: AIF is a technology that enables the implementation of alcohol interlock programmes, which have been shown to be an effective measure to reduce instances of drink driving, particularly by repeat offenders. ISA is effective at helping drivers to adhere to speed limits, so instances of speeding will be reduced. As the system can be deactivated by drivers, there is, however, a likelihood that the effect on drivers speeding wilfully and substantially could be limited.

	Adverse			**Neutral**			**Beneficial**
	−3	−2	−1	0	+1	+2	+3
Appraisal					■		

D.5.3.4 Access to justice

ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
×	×	×	×	×	×	×	×	☑	×	×	×	×	×	×	×	×	×	×

To determine culpability in case of a road traffic collision, courts rely on witness statements and evidence collected by police or private collision investigators (such as marks at the scene). This evidence is not always conclusive in which case objective EDR records of vehicle movements and driver actions before a collision could aid courts in their proceedings and enable justice to be delivered. Dashcam footage cannot fully replace the detailed records of an EDR and dashcams are fitted to only approximately 20% of vehicles in GB.

	Adverse			**Neutral**			**Beneficial**
	−3	−2	−1	0	+1	+2	+3
Appraisal						■	

D.5.3.5 Affordability

ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
☑	×	×	×	×	☑	☑	☑	×	☑	×	×	×	☑	×	×	×	×	×

Mandatory implementation of new technologies will create costs for vehicle manufacturers. To what extent these costs can and will be passed on to vehicle purchasers depends on complex factors, including the level of competition in the market, but it cannot be ruled out that the purchase prices of vehicles would increase and therefore decrease the affordability of new vehicles. The overview above highlights all technologies for passenger cars that individually cost around or more than £100 per vehicle.

This aspect may be considered to have potential PSED relevance with regard to the protected characteristic 'age' because young people before or at the start of their working life as well as older people after their working life might be more negatively affected. However, the above groups can be expected to mostly buy lower segment cars on the second-hand market and will therefore, over time, also benefit from the increased safety of cars in the more affordable segments, which may otherwise not be equipped.

	Adverse			**Neutral**			**Beneficial**
	−3	−2	−1	0	+1	+2	+3
Appraisal		■					

D.5.3.6 *Accessible vehicles*

ADW	AIF	BSI	DAW	DIV	EBC	EBP	EBV	EDR	ELK	ESS	FFI	FOI	ISA	MOI	PSI	PWI	RMA	TPM
☑	×	×	☑	×	☑	☑	☑	×	☑	×	☑	☑	☑	×	☑	×	☑	×

Drivers with disabilities may require specifically modified vehicles, which are typically built by converting conventional vehicle types. The modifications required to make vehicles wheelchair accessible or cater for drivers' motor disabilities can be manifold and often involve substantially altering the vehicle. Depending on the nature of the conversion, it may be necessary to make structural changes to the vehicle or adapt/disable some of the active vehicle technologies considered.

This aspect has PSED relevance with regard to the protected characteristic 'disability'. When developing implementing legislation to make certain technologies mandatory, it is recommended to consult, with appropriate stakeholders, on potentially required exemptions for wheelchair accessible or otherwise converted vehicles for disabled users.

	Adverse			**Neutral**			**Beneficial**
	−3	−2	−1	0	+1	+2	+3
Appraisal			■				

D.5.4 Public accounts impacts

Public account impacts cover the costs borne by public bodies. No unquantified secondary impacts have been identified.

Appendix E Comparison of GB and EU cost-benefit analyses

The EU has already mandated the vehicle safety technologies considered in this study via the General Safety Regulation (EU) 2019/2144. This appendix provides a high-level comparison of the EU CBA (Seidl M, 2017), which underpinned the European Commission's impact assessment for the General Safety Regulation, with the present GB CBA, focussing on scope, assumptions and results.

E.1 Scope

The scope of vehicle technologies analysed for the EU CBA was similar to this GB CBA, but not identical:

- The technologies BSI and MOI as well as EBC and EBP were considered as a single technology, respectively (note: this does not affect results).
- EDR implementation was only considered for M1 and N1 vehicles, but not for M2M3 or N2N3.
- For FFI, introduction of a new crash-test dummy (THOR-M) and lower injury criteria thresholds was considered, but it is unclear if or when this will be realised at UNECE level, which is why it was not considered for this GB CBA.
- FOI implementation for N1 was not considered.

The scope of impacts considered for the EU CBA was limited to casualties prevented and technology fitment costs. This GB CBA additionally considered collisions prevented, emissions prevented, journey time saved, reductions in fuel and energy consumption as well as technology maintenance and repair costs.

The vehicle categories considered for the EU CBA included minibuses, which were not considered in this GB CBA due to data limitations (see Section 3.3).

E.2 Assumptions

The appraisal period chosen for the EU CBA was two years longer and starting four years earlier.

For most of the technologies considered, technical regulations did not exist at the time the EU CBA was carried out. There are some differences between the technical capabilities assumed and those implemented subsequently in regulations and considered for this GB CBA:

- ADW only detects distraction (not required to detect drowsiness).
- BSI only detects cyclists on the vehicle's nearside (not required to detect pedestrians, not required to cover offside).
- DAE only detects drowsiness (not required to detect long-lasting inattention/distraction).
- EDR records more data elements.

- ISA likely to be realised with map-support in parts of the fleet (rather than camera-only).
- RMA likely to be realised with detection systems in parts of the fleet (rather than camera).

The technology fitment costs estimated for the EU CBA were about 30% lower compared to this GB CBA.

The effectiveness estimates at preventing casualties were based on different studies for some technologies: AIF, EBC, EBP, EBV, FOI and ISA.

E.3 Results

The EU CBA analysed three different technology packages (referred to as 'policy options') while this GB CBA analysed seven. The most comparable package is the one containing all technologies in scope, i.e. PO3 from EU CBA and TP1 from GB CBA. Table 93 presents the BCRs found for this package in both studies. Note the differences in technologies contained discussed above (Appendix E.1) and the considerations on M2M3 results presented in Section 4.1.2.

Table 93: BCRs of 'all technologies' package from EU CBA and GB CBA

	BCR of EU CBA, PO3	BCR of GB CBA, TP1
M1	1.4	4.8
M2M3	2.1	42.0
N1	0.5	3.5
N2N3	1.0	8.7
Total	***not calculated***	**5.4**

Cost and benefit analysis of new vehicle safety technologies

The objective of this study was to quantify the benefits and costs that would arise from mandating the fitment of up to 19 vehicle safety technologies to new cars, vans, lorries, buses and coaches in Great Britain. This will provide the Department for Transport with an evidence base to develop policy options for ministers that are cost-effective and impactful for Great Britain in order to enable safer and cleaner transport while minimising the negative impacts.

This cost-benefit analysis has been undertaken to determine the impacts that would arise from seven interventions, i.e. mandatory implementation of different technology packages, compared with the business-as-usual case, i.e. continued voluntary adoption of the technologies in parts of the vehicle fleet in a market environment where technologies are mandatory in the EU for the same vehicle categories. The study quantified and monetised safety, environmental and traffic benefits, and fitment and maintenance costs over a 15-year appraisal period extending from 2025 to 2039.

It was found that all seven packages bring benefits outweighing the costs with BCRs between 4.3 and 5.7, i.e. provide very high value for money, and take advantage of synergies between different technologies, such as lower costs due to sensor sharing, when implemented jointly. Over the entire appraisal period, the packages may be expected to prevent between approximately 5,000 and 14,000 killed or seriously injured casualties on Great Britain's roads depending on the technology package selected and when compared to business as usual.

Other titles from this subject area

DOI 10.2873/748910	In depth cost-effectiveness analysis of the identified measures and features regarding the way forward for EU vehicle safety. M Seidl, D Hynd, M McCarthy, P Martin, R Hunt, S Mohan, V Krishnamurthy and S O'Connell. 2017.
DOI 10.2873/304129	Cost-effectiveness analysis of Policy Options for the mandatory implementation of different sets of vehicle safety measures – Review of the General Safety and Pedestrian Safety Regulations. M Seidl, R Khatry, J Carroll, D Hynd, C Wallbank and J Kent. 2018.
TRL PPR766	The potential for vehicle safety standards to prevent road deaths and injuries in Brazil. R Cuerden, L Lloyd, C Wallbank and M Seidl. 2018.

TRL
Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

PPR2077